A handbook of geoarchaeological approaches for investigating landscapes and settlement sites

Charles French

STUDYING SCIENTIFIC ARCHAEOLOGY 1

A handbook of geoarchaeological approaches for investigating landscapes and settlement sites

To Francis Pryor and Richard Macphail
– for pointing me in the right direction

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Front cover: The author taking soil blocks for micromorphological analysis from buried floodplain soils of about 4500 years old in the Rio Puerco valley of New Mexico, USA
Back cover: Soil sampling on a systematic grid from an exposed floor level in an Hispanic period house at Sangayiaco in the upper Ica valley of Peru (C. French)

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Preface

This short book owes itself to all my students and whoever has worked with me in the field and in the lab since 1979. In class at Cambridge I am often asked: "where can I find this basic methodological approach stuff" and I have to reply "it is spread about in various case studies and textbooks." Consequently this handbook aims to explain some of the basics of geoarchaeological approaches and research design used to tackle the investigation of landscapes and settlement archaeology, and the application of soil micromorphology to archaeological situations, each with a few good examples. The intention is to present a handbook of basic good practice that any archaeologist or aspiring geoarchaeologist can use, rather than be a textbook with all the data and answers.

It was not until I worked for Francis Pryor on the fen-edge of Cambridgeshire at Fengate from 1975 that I had actually saw a buried soil that I was able to recognise. Prior to then, most of us had probably seen them as an horizon change, but thought little of it and had certainly not recognised their significance. But it was later during the Maxey and the Etton/Etton Landscape projects from 1979 and English Heritage's Fenland Project on the Southwest Fen Dyke Survey project that I really began to see the importance of buried soils and their essential role in interpreting landscape settings, processes and transformations. Moreover, the analysis of buried soils and the evidence contained within them are able to give multiple reflections on past human activities and land-use changes.

This naturally led me into the science and application of soil micromorphology. This transpired through an opportunistic meeting with Richard Macphail in the spring of 1983 in the 3rd floor Environmental Laboratory at the Institute of Archaeology in London. Richard, just recently hired as English Heritage's soil specialist for southern England, asked what type of sites I was working on. As soon as I said buried soils under Neolithic and Bronze Age barrow mounds, he said that I should definitely do some soil micromorphology! Needless to say, I have not really looked back since.

It goes without saying that I would not be here if first Francis Pryor had not hired me as a digger in 1975, and then Richard Macphail had not introduced me to soil micromorphology in 1983! So, this handbook is dedicated to them.

2 April 2015

1. Introduction

Geoarchaeology is a major branch of archaeological science at the interfaces between geology, geography and archaeology. It involves the combined study of archaeological, soil and geomorphological records and the recognition of how natural, climatic and human-induced processes alter landscapes. Geoarchaeology is equally important at the macro-scale of land-use and landscape change as at the meso- and micro-scale for the use of space and human activities in a settlement context. For all scales it is possible to investigate the formation and modification of past soils and occupation sequences, primarily through the use of soil micromorphological techniques (or the study of soils and sediments in thin section) and various physical and geo-chemical techniques.

The geoarchaeological approach can tackle just about any landscape or site, anywhere in the world, and from any time period. This may be a highly altered landscape such as the late glacial lake to early–mid-Holocene palaeosol/hillwash/calcitic lake/hillwash sequence in northern Tierra del Fuego (McCulloch *et al.* 2005; Morello *et al*. 2012) (Fig. 1), or the deeply buried former dryland landscapes on the margins of the East Anglian fens (French 1988a; 1988b; 2003; French and Pryor 1993; 2005), or a small relict survival of a past landscape preserved beneath upstanding monuments such as at the Gussage Cow Down Neolithic long barrow in Dorset (French *et al.* 2007). It may also be widely applied to settlement sites wherever there is a build-up of occupation material, such as the Viking period trading hamlet at Kaupang, Norway (Skre 2007; Milek and French 2007), whole urban towns such as Hellenistic Beirut (Boivin and French 1997–8) or the late 3rd millennium BC town of Saar in Bahrain (Matthews and French 2005) and deeply stratified tell sites such as Tell Brak in Syria (Matthews 2003; Matthews *et al*. 1998; Wilkinson 2005); or to individual structures such as Eneolithic earthen sunken floored dwellings at Botai, Kazakhstan (French and Kousoulakou 2003) or Neolithic stone structures at Crossiecrown Farm (Jones *et al.* 2010) or Barnhouse (French 2005) in Orkney and under hillwash and henge bank deposits at Durrington Walls in Wiltshire (Fig. 2) (French *et al*. 2012).

Wherever there is a buried old land surface or soil present, it usually contains signatures of the events that have affected it through time and these have a bearing on how the wider surrounding landscape was shaped through time. To briefly define what is a ***soil*** – it is an organic/inorganic material developing through the weathering of the subsoil by physical and chemical processes through time, whereas a ***sediment*** is any

Fig. 1. The shoreline sequence on the south-western side of Inútil (or Useless) Bay, northern Tierra del Fuego, illustrating an Holocene sequence of recent colluvial deposits over laminar calcitic lake deposits with more hillwash deposits below, all overlying a buried soil sequence on the edge of a former late glacial lake (R. Scaife)

Fig. 2. The late Neolithic house floors on the eastern side of the Durrington Walls henge, Wiltshire, England (C. French, with permission of M. Parker Pearson)

inorganic/organic material, from an organic mud to fine clay to a coarse rock, which has undergone weathering, transport and redeposition by various geomorphic agencies. All soils (and buried soils and palaeosols) and sediments contain distinctive signatures of past environmental changes and thus are very useful in deciphering both natural and/or human-induced landscape change. It is often possible to distinguish for example: woodland and clearance, ploughing, manuring, middening, flooding, truncation and erosion and deposition processes such as hillwash and alluviation (Goldberg and Macphail 2006; Stoops *et al*. 2010). Thin section micromorphology as applied to soils and sediments is adept at identifying and explaining those features characteristic of these events and processes, and enabling the construction of sequences of land-use and landscape change. Essentially, intact blocks of soil or sediment are taken in the field, and in the laboratory are first impregnated with resin, then sliced and mounted, ground and polished on a large format microscope slide to a thickness of about 25–30 microns, and then described and analysed using a polarising microscope (see Appx 3).

When there are structures discovered on an archaeological site and there is a good level of preservation revealing extant floors or occupation deposits, thin section micromorphology and geo-chemical analyses (see Appx 1–3) may be used in combination with the artefactual and palaeo-environmental analyses to investigate the spatial signatures of human activities in built space. For example, at Durrington Walls in the southern English chalklands, Late Neolithic midden deposits sealed beneath the chalk rubble henge bank revealed sequences of dumping of food refuse and hearth rake-out, and thin, multiple chalk slurry floors were present in small sub-square wooden structures but with no occupational debris present (Figs 2 and 3) (French *et al.* 2012; French forthcoming a). At Catalhoyuk, thin section analyses have revealed repeatedly applied and painted fine wall plasters, and multiple coarse/fine floor plasters with and without the accumulation of organic occupation deposits and/or herbivore stabling deposits for example (Matthews 2005; 2010; Matthews *et al.* 1996; 1997a). Or, a human activity may be sampled for comparative and explanatory purposes from a possibly analogous ethnographic situation, such as a threshing floor in Israel or Greece (Shahack-Gross *et al.* 2009) or the mud-brick of abandoned earthen dwellings in the Bolivian highlands (Goodman-Elgar 2008).

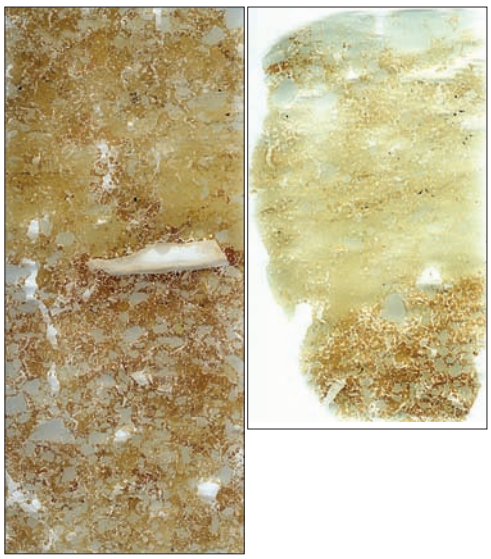


Fig. 3. Two views of the fine chalk slurry floor of a small rectilinear house over a truncated rendzina soil at the late Neolithic Durrington Walls henge (left = 12.5cm in length; right = 8cm in length) (C. French)

Importantly, micromorphology used within a wider geoarchaeological approach can be integrated with archaeological and palaeo-environmental data to give

both landscape and site-specific sequence data (Courty *et al*. 1989; 1994; French 2003; Goldberg and Macphail 2006). This too may require experimental and/or ethnographic studies to see how soils behave when affected by specific human or natural events. For example, much work has been done on the effects of arable plough agriculture on soils, both in the present (Jongerius 1970; 1983) and in the past (Gebhardt 1992; 1995; Lewis 1998; 2002; 2012). Together these types of studies dramatically enhance our information return on interpreting past climate-landscape-human-settlement dynamics.

This handbook develops these themes and tries to show the reader the basics of how to think about and conduct geoarchaeological and micromorphological studies of archaeological sites and landscapes within a wider palaeo-environmental context. It builds on a number of good existing guides to using soil analytical techniques in archaeology, including the soils handbook of Keeley and Macphail (1981), Bridges (1978) world soils textbook, Limbrey's (1975) textbook on different types of soil formation observed in Britain and Europe, and English Heritage's guides to geoarchaeology (2007) and environmental archaeology (Campbell *et al.* 2011). Perhaps not every aspect is covered, and it is not meant to be a 'recipe' book, but some viable approaches are presented that work to provide essential information on integrated landscape and site development, anywhere in the world.

2. Approaches to investigating landscapes

This chapter sets out various approaches that may be used to decipher and model past landscape histories, as well as some of the problems and biases involved in their interpretation. The essence of this approach is to move away from investigating sites in isolation to viewing them as being integral with their contemporary soils and their surrounding landscape. This system is dynamic with a number of relationships, often inter-dependent, between people, climate and their environment.

Initially, we must also consider what we mean by the term *landscape*. In Japan, landscape means 'the background' and in Korea it is the 'outline of something' whereas in China it is a 'view.' Similarly in England, we may talk about 'the background landscape,' but it is a term full of connotations with multiple variations depending on the perception of the person viewing or using that landscape. It may be something 'earthy' or a view with the landowner and his dog, or it may be the hill-walkers barren fell-side or 17th/18th century estate parkland, all of which are transformed landscapes, or products of interference, use and management by people. But in the end what probably matters most is the notion of knowing what is going on between "people and their surroundings" (Evans 1999, 6; after F. E. Zeuner), and the interactions and changes occurring over time.

First, what is the nature of the evidence? Well, it is ***all*** the available evidence that you can discover (Table 1). The questions then are:

- How do you go about choosing the most suitable types of evidence for investigation?
- Where do you look for this evidence?
- What are the constraints on the preservation, retrieval and interpretation of this evidence?
- How do you construct a research design to extract the best possible evidence, within a reasonable time-frame and budget?

The approach must be wide-ranging and above all, flexible in execution. At the same time, the approach must be targeted to specific questions, in other words, critically applied to the problem at hand. Needless to say, the questions being asked are often flavoured by the research views and directions of the day, and/or driven by different agendas and the interests of the archaeologists involved, and whether it is a research or a developer-funded project.

Valley systems are most often the favoured unit of study in landscape archaeological projects and their associated gearchaeological studies. This unit of landscape is defined by the drainage watershed over any length of valley or segment of valley (Evans and O'Connor 2005). But of course it may be defined by other boundaries such as local political units or a specific development area such as a quarry, housing development or road bypass, or some combination of these. Typically valley systems may include well defined basin mires, such as in the East Anglian fenland, or a length of river valley with its associated floodplain and gravel terraces, both covered by alluvial or flood deposits or remaining unalluviated, and the adjacent higher ground on hard rock geology. Well-studied examples of these in England include the lower Welland valley of north-west Cambridgeshire (Pryor and French 1985; Pryor 1998; French and Pryor 2005), the lower Nene and fen-edge on the eastern side of Peterborough (French and Pryor 1993; Pryor 1978; 1980; 1984; 1992; 2001; Evans 2009), the lower Great Ouse and fen-edge north-west of Cambridge (Evans and Hodder 2006a; 2006b; Evans and Tabor 2008; Evans *et al.* in prep.; French in prep.) and the Thames valley around Oxford (e.g. Eton Rowing Lake; Cromarty *et al*. 2006). In other parts of southern England, river valleys in chalk downland landscapes are commonly investigated, such as the upper Allen valley south-west of Salisbury (French *et al.* 2007), the Avon valley between Durrington Walls and Stonehenge to the north of Salisbury (French *et al*. 2012; Parker Pearson *et al*. 2004; forthcoming), and the A35 Bypass around Dorchester (Hearne and Birbeck 1999).

Valleys come in a variety of forms and topographies, but are generally suitable study units for the related investigations of landscape history and human development. They have distinctive topographies and climates, often with considerable range and micro-variability, which support different vegetational regimes, often varying markedly from one side of the valley to the other (Evans and O'Connor 2005). Also they are subject to erosion, burial and aggradational factors, and these have boundaries as well as recognisable energy and depositional pathways (Butzer 1982; Gerrard 1992; Schiffer 1987). Thus, it is necessary to think of an open system with physical/chemical transformations of matter going on within the system over time, with and without human involvement and/or manipulation. As geoarchaeologists, we need to be able to chart these changes and investigate the reasons why they occurred as accurately as possible, and relate these to the dynamics of human and/or climate induced landscape change.

In studying past landscapes, what are geoarchaeological studies trying to achieve? First, it is essential to understand the interaction of soil development, rainfall, run-off rates and erosion, vegetational change and human activities, and their combined roles in shaping the valley system that is observed today. Second, one is aiming to develop chronosequences and palaeo-catenas that can be used to estimate the age of surficial deposits and relate these to human settlement and living activities in that region, and discern the sequence of how that landscape has developed and been utilised through time. It is essential to know how long it has taken to form key properties and deposits in different environments, and/or when major changes/transformations occurred, whether culturally and/or environment-driven. Third, soils and vegetation

Table 1: Major sources of proxy data and what they may tell us about

Data source	Variable measured	Inferences about
Geology	weathering indices, base status, hydrology	soil formation, drainage pattern, preservation factors
Geomorphology	tectonics, coastlines, fluvial inputs and outputs	eustatic/isostatic uplift/ subsidence, landscape formation including shoreline development and river valley avulsion
Palaeosols	soil formation and processes through time	soil types and soil change sequences, environment and vegetation complex, natural versus human impact signatures, human activities
Waterlogged deposits	hydrology, redox, dissolved oxygen, rainfall, vegetation, invertebrates, insects, pollen, plant macro-fossils, charcoal, wood, diatoms, foraminifera	vegetation composition and sequences, erosion and aggradation, groundwater tables, water quality, preservation context
Human settlements	food production, storage and disposal, cooking and rubbish disposal, activity types and areas	changing production, consumption and lifestyles
Modern and ethnographic analogues and experimental data	possible factors and rates of change governing any natural, environmental or human-induced process, activity or system	natural processes and human impact, rates of change

types can be used as indicators of long and/or short-term stability or instability, and consequently may be used to show how they have shaped and/or reflect cultural development and change through time? Fourth, is it possible to determine the evidence for and indicators of climatic and/or human impact on land-use change, and discern how these may have influenced landscape development and human activity narratives and biographies? Finally, from these datasets and interpretations, is it possible to understand environmental-human interactions, and give answers as to why any observed changes may have occurred?

Theoretical and methodological considerations

A number of proxy records are regularly used by archaeologists as indirect measures of climate and environment (Table 1). These primarily include the analysis of pollen, plant macro-fossils, faunal remains, soils and sediments, and more rarely insects and phytoliths, as well as tree rings, sea level change and isotopic signatures reflecting past rainfall and temperature regimes (Bell and Walker 2005; English Heritage 2007; Campbell *et al*. 2011). Regularly augmenting these datasets are dating programmes, historical climatic and meteorological data, other historical records and maps, ethnographic records and/or experimental data (Bell and Walker 2005). This type of combined archaeological and environmental approach has a long tradition of application in Britain, perhaps best exemplified initially by the studies of Cambridgeshire and Britain by Sir Cyril Fox (1923 and 1938, respectively) and the development of the British/English landscape espoused by Hoskins (1955) and more recently by Evans (1999) and Pryor (2010).

Proxy data relies heavily on modern analogues, with 'the present as the key to the past' as its central tenet. This is underlain by several assumptions. The uniformitarian approach (Hutton 1788) rests upon the notion that knowledge relies on observed experience. As a consequence, scientific statements acquire meaning through their empirical basis (observational and experimental as opposed to theoretical), and the generalisations which form the basis of scientific laws are derived from repeated observations of reality. Once theories or laws are established in this manner by repeated data, there is a basis for prediction and/or explanation by means of deduction. This ethos now demands much scrutiny, verification and replication of results, and we are much more likely to deal in probabilities rather than absolutes.

In contrast, Popper (1972) viewed the deductive approach as based on tentative conjectures which were then tested through observation, experimentation and measurement. Those that fail are replaced by others and tested again. Thus, science proceeds by trial and error. This inductivist approach championed the accumulation of knowledge which relied on experience, and hence scientific statements acquired meaning by virtue of their empirical basis. Again, this can be unsatisfactory and often circular in argument. Now it is much better to consider our work as producing inferences based on a series of converging datasets, often backed up by experimental and ethnographic analogues, and woven into a cultural milieu through time.

In addition, environmental determinism has often been a constant, if sub-conscious, underlying basis for many archaeologists and palaeo-environmentalists investigating landscape change. I have been as guilty of this as many others in the past. For example, I once suggested that a Bronze Age field system situated on the Fengate fen-edge of northern Cambridgeshire was abandoned as a result of freshwater flooding, on the basis of the observation of a single flood-silt fill horizon in a series of contemporaneous 2nd millennium BC ditches (French 1980; Pryor 1980). This paid little heed to other possible influencing factors such as wider and longer-term sub-regional events, both cultural and environmental, regional and local changes in land-use or settlement pattern, and the socio-economic drivers of the management of this agricultural landscape, past and present.

Several core problems underlie all landscape studies, in particular the nature of ecological change as reflected in some data assemblages and the long-term dewatering

of landscapes. Although the most drastic environmental changes often occurred during glacial times and the transitions to interglacial periods, once into the Holocene the vegetational changes that have occurred since the Mesolithic period have had a huge effect on the ecology of many plant and animal species. Primary among these effects is the disappearance of woodland and the appearance of human settlements and extensive agricultural landscapes. For example, there are few real woodland faunas and floras remaining in England. Modern analogue ecological systems for comparison are few and far between (Davies 2008). Some species have adapted well to the changing environment of grass to woodland to agriculture, and others have had their habitat distributions altered irretrievably, some have become extinct and a few others have thrived in the habitats created by humans. For example, some molluscan species in Britain such as *Columella columella* are really only present in late glacial deposits (Kerney and Cameron 1979; Preece and Bridgland 1999). Some woodland snail species have either disappeared by Neolithic times, such as *Lauria anglica*, or become anthropophobic, such as *Ena montana*. Only a few species such as *Pomatias elegans* have been able to adapt well to clearance and the disruptive effects of plough agriculture, or to bare, disturbed ground such as *Pupilla muscorum* (Evans 1972, 123–130; Thomas 1985; Davies 2008, 59–60), and a few others such as *Trichia striolata* which are synanthropic species now living in gardens, farm yards and refuse heaps, not in woodland as in pre-Neolithic times (Evans 1972, 128).

Dewatering and desertification, intricately entwined with the rise of western culture and tourism, have recently become recognised as both major factors and symptoms of environmental change. Indeed they affect every other form of life on the planet. For example, millions of hectares of wetland have disappeared through drainage schemes and extensive arable cultivation in north-west Europe in the past few hundred years, none more so than the East Anglian fens of England, particularly since World War II and the 'Dig-for-Victory' campaign (Coles 1995; Hall and Coles 1994; Pryor 2010). Around the margins of the Mediterranean Sea, land which was once at least partially wooded in earlier prehistoric times, has become increasingly marginal and prone to thunderstorms, soil erosion and deep valley or arroyo incision as a combined response to longer term climate change and aridification over the past 4000 years (Brown 1999; Castro *et al*. 1998; French 2010c; Thornes 2005; 2007; Van Andel *et al*. 1990). The massive growth of a tourism industry in the past 50 years coupled with unsympathetic, imposed agricultural policies have only served to exacerbate the problem. In both cases, the landscapes present in the earlier Holocene cannot just be reinstated through re-wetting, and even drastic conservation measures may do little more than slow the decline into desert-like 'badlands'.

There are a number of other considerations which must always be present in our minds. For the bio-archaeological and soil evidence, how is the living community transformed into a fossil assemblage? What processes and transformations have affected the assemblage in life, in death, during and after burial? The Overton Down experimental earthwork (Fig. 4) on calcareous chalk bedrock (Bell *et al.* 1996) and the Wareham site on a substrate of acidic sands (*ibid*.) in southern England are great experimental examples for tracking the possible time-lines of all sorts of processes, transformations and preservational problems of individual sources of archaeological and

Fig. 4. The bank and ditch at Overton Down experimental earthwork, Wiltshire, England (C. French)

palaeo-environmental evidence. For example, pollen within the turf core disappeared in the first 6 years after burial at Overton but not at Wareham (*ibid*.). Textiles were gone after 3 years through microbial attack, but molluscs and bone survive at Overton. The molluscs living in the pre-bank grassland live and die in the same context, but the small shells are easily susceptible to earthworm mixing upon death and further incorporation into the buried soil and subsequent mixing and movement at various depths. Other experiments have suggested that small biological data such as snails and rodent bones (and by implication therefore pollen grains and phytoliths) in calcareous soils may move as much as 30 cm up and down and at least a similar amount side to side (Armour-Chelu and Andrews 1994). Thus no amount of fine incremental sampling will correct for this past biological mixing (or bioturbation). Indeed it would produce spurious evidence of dubious accuracy! If this same soil was ploughed before burial, movement of artefacts could be as much as 70–100 cm side to side and up and down (Boismier 1997). More worryingly, soil and vegetational change can occur very fast, and may essentially be beyond the resolution of any dating technique currently available to us, that is within less than a generational scale. For example, in the fenced compound around the experimental earthwork at Overton Down, the lack of management and grazing by sheep has led to soil change from a thin grassland rendzina on chalk to a thickening stagno-gley on chalk during the life-time of the earthwork, thus within about 50 years (R. Macphail, pers. comm.). Who would have guessed at soil change taking place within a generation and the error margin of a radiocarbon date, through the absence of human intervention and no management of the grassland vegetation!

Factors affecting archaeological recovery and environmental evidence

So, how do environmental factors modify cultural and palaeo-environmental residues and bias preservation? Rainfall, run-off, wind, slope angle, the amount of vegetative cover and soil type all play a role in the transport and redeposition of soil and sediment, as do the nature and intensity of human activities. Without wishing to reiterate the content of many good textbooks on the subject (e.g. FitzPatrick 1986; Goudie 1990; Limbrey 1975; Rapp and Hill 1998; Waters 1992), there are some elementary concepts that will be touched briefly upon here as they are essential to understanding contexts of deposition and formation in landscapes.

Erosion tends to reach a maximum in areas with a mean annual rainfall figure of about 300 mm or less (Langbein and Schaum 1958). Rainsplash is considered as the most important detaching agent and contributes considerably to run-off. Medium and coarse sand-size particles are the most easily detached from the soil mass, whereas clay resists detachment (Farmer 1973). For example in the lower Welland valley of temperate eastern England, where annual rainfall varies between 500 mm and 600 mm per year (Burton 1981), the greater vegetative cover in the higher parts of this landscape may counteract the erosive effect of greater rainfall whereas the large proportion of open arable fields on sloping land with about 15–20° of slope in the western part of the survey area is more erosion prone (Pryor and French 1985, 2–5). In contrast, short-lived, intense storms and prolonged storms of low intensity have the greatest erosive effect (Morgan 1979), especially when combined with semi-arid to arid climatic conditions (Cooke *et al*. 1993; Goudie 1990). For example overnight gully formation in the lower Aguas river valley of south-eastern Spain is a good case in point for the severe effects of intense storm events (French *et al*. 1998; French 2003, fig. 13.7; French 2010c), as is the 11+ m of incision through cumulative alluvial deposits in the Rio Puerco valley of New Mexico since the 1880s (Fig. 5) (French *et al.* 2009b).

Fig. 5. The deeply incised Rio Puerco river system, New Mexico, USA, created since the 1880s (C. French)

Surface run-off or overland flow occurs on hill-slopes when the soil's infiltration capacity is exceeded (Kirkby 1969a; 1969b; Selby 1993), even under woodland (Imeson *et al*. 1980) (Fig. 6). An absence of vegetation or bare and/or ploughed soil surfaces makes any resistance much worse (Kwaad and Mucher 1979). Horton (1945) suggested that overland flow (hillwash or colluvial) deposits can cover two-thirds or more of the bare hillsides of a drainage basin during the peak period of a rainstorm. Grains of *c*. 0.5 mm in diameter (or fine sand-size) are the most easily moved, whereas smaller and larger grains require a much higher threshold velocity. Silts with low infiltration capacity and cohesiveness (i.e. poorly structured) and low organic component are more susceptible to mass movement, but fine grains are not redeposited until very low flow velocities are reached (Morgan 1979). In contrast, sub-surface soil water flow only erodes about 1% of the total material from a hillside (Kirkby 1969a).

A proportion of the hillwash derived, eroded soil and sediment material ends up entrained in the main river systems and is often redeposited overbank by seasonal flood events as alluvium (Fig. 7). This material tends to be well-sorted, homogeneous and of various size grades, but is commonly silt and clay material such as found deposited in most lowland English river valleys (Brown 1997; French 1990; 1998; French and Pryor 2005). In floodplain situations, alluvium is regularly responsible for burying large areas of former dryland, generally on lower river gravel terraces (Howard and Macklin 1999). These were often the focus of earlier prehistoric ceremonial, burial and settlement activity, such as in the lower Welland valley of Cambridgeshire (French and Pryor 2005; Pryor 1998) and the lower Aguas valley of south-eastern Spain (French *et al.* 1998). Burial with alluvium both protects and seals old land surfaces from later physical disturbance and preserves buried soils (Fig. 8), and may also exclude air and be associated with high groundwater tables which leads to much better preservation of the full archaeological and palaeo-environmental record. Nonetheless, severe flood

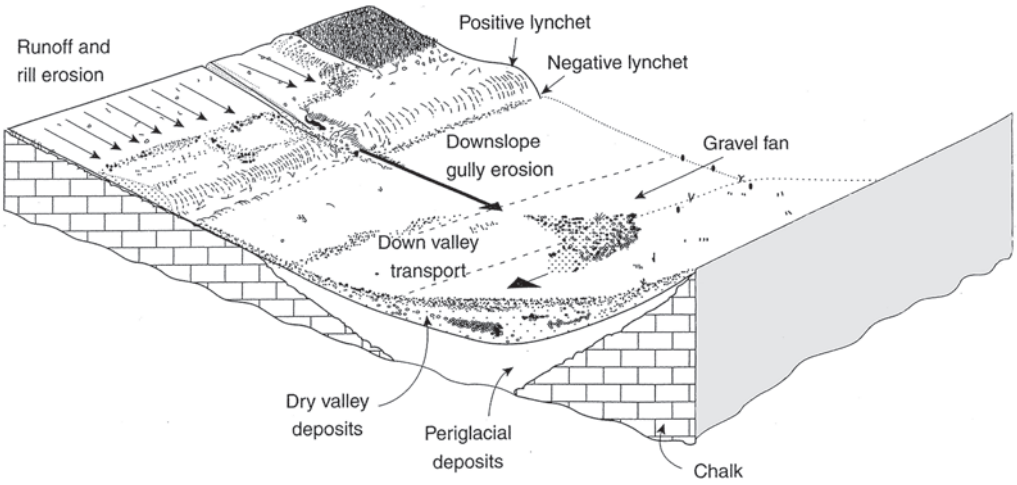


Fig. 6. A schematic diagram of a colluvial landscape (with permission of M. J. Allen)

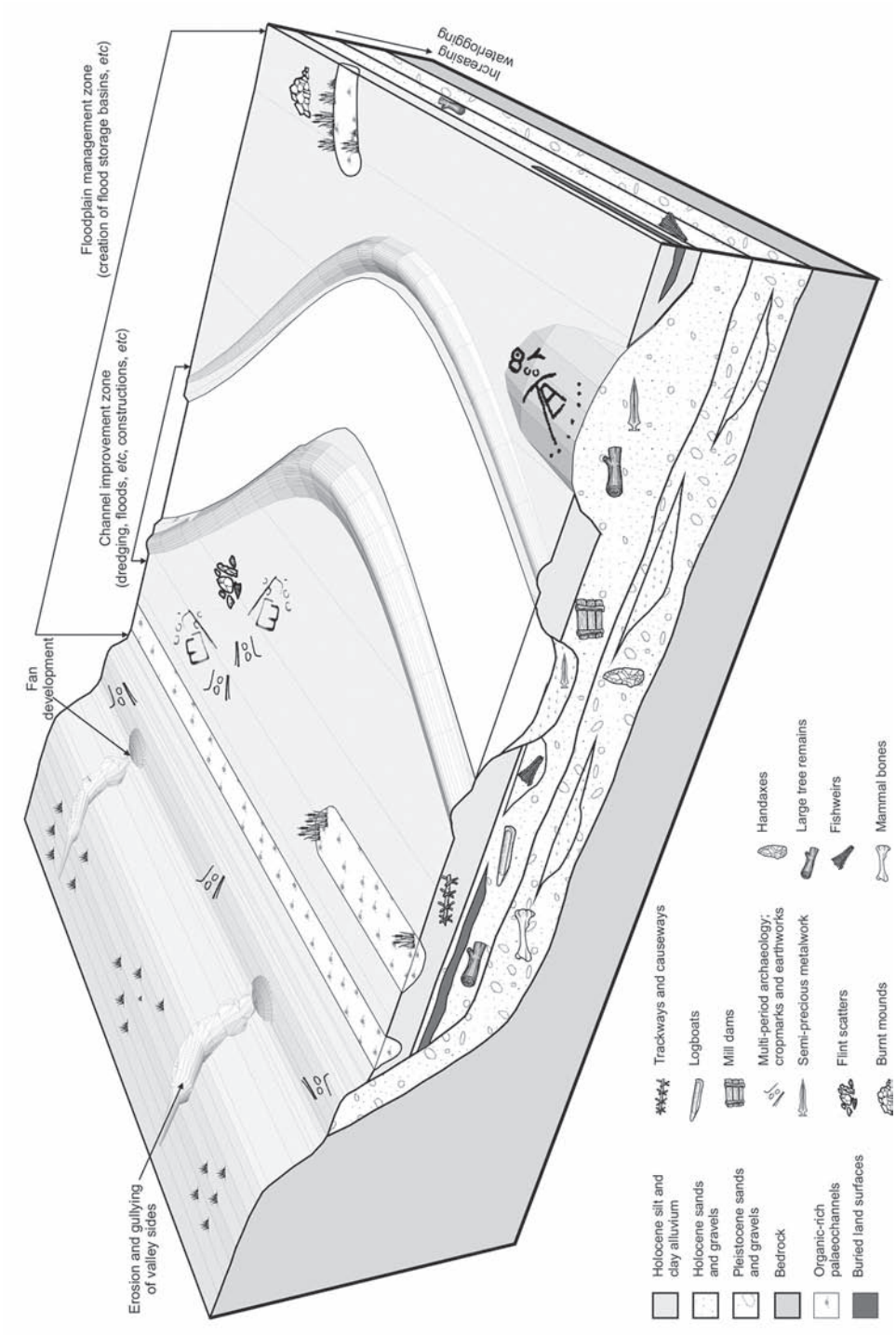


Fig. 7. A schematic diagram of an alluvial landscape (D. Redhouse, adapted from A. G. Brown 1997, fig. 1.1)

events and repeated groundwater fluctuations in these floodplain alluvial environments can also lead to detrimental preservation of much of the organic and archaeological records through repeated wetting and drying processes (Brown 1997; Statham 1979; Waters 1992).

Wind is also a transporting agent. Critical wind velocities that are required to move soil particles vary, but are least for particles with a diameter of 0.1–0.15 mm (fine silt), and increase with increasing and decreasing grain size (Morgan 1979). Transport by wind occurs in suspension in air over long distances, especially for fine material of <0.2 mm in diameter (or fine silt and clay), by surface creep or rolling along the ground, and by saltation of a series of jumps (*ibid.*). Probably the most extensive sources of wind-blown material are areas of fluvial sediments which are deposited after infrequent but intense storms (Statham 1979; 1990), and glacial deposits under peri-glacial conditions that are a source of silt-size loessic material (Catt 1978; 1979). For example in much of central Hungary, several metres of loessic deposition has occurred since late glacial times, and this has often been reworked, eroded and redeposited in more recent prehistoric times as a consequence of farming activities by Bronze and Iron Age peoples and again in historic times (Fig. 9c) (French 2010a).

The effect of slope is to increase erosion with increasing slope angle (Kirkby 1969a). Forces such as gravity, frost heave, rainsplash, soil texture, water content and vegetative cover help produce erosion on slopes. This results in slope wash, and mass movements such as mud or overland flows, and solifluction down-slope of both fine and coarse material (Clark and Small 1982). For example within the centre of the late Neolithic

Fig. 8. Silty clay alluvium aggrading in the River Nene floodplain and encroaching over a late Neolithic–early Bronze Age barrow ditch and mound, Orton Longueville, Peterborough, Cambridgeshire, England (C. French)

henge at Durrington Walls, Wiltshire, at least 2 m of chalky hillwash has accumulated over the buried soil associated with the Southern Circle of wooden posts (Fig. 9b) (French *et al.* 2012). In the Dhamar region of highland Yemen, eroded soil generated by prehistoric agricultural exploitation has buried prehistoric soils over large areas of landscape since the Neolithic (Fig. 9d) (Wilkinson 2005).

Sometimes a combination of episodic wind-blow and hillwash aggradation may bury and sandwich archaeological horizons and sites. A good example of this was discovered at Brean Down in Somerset (Bell 1990). Here a series of Bronze Age settlement areas was buried by both wind-blown sand derived from an exposed foreshore at low-tide, as well as successive phases of hillwash from upslope associated with human exploitation of the surrounding chalk slopes (Fig. 9a).

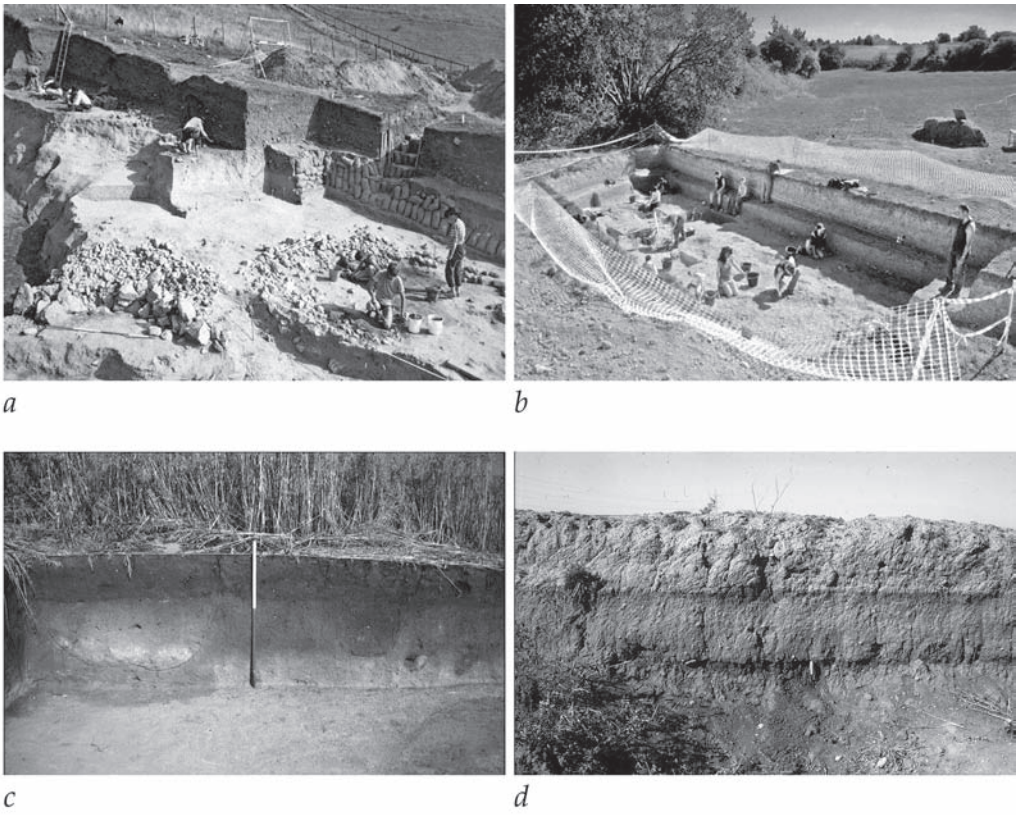


Fig. 9. Examples of hillwash sequences: a) Repeated palaeosol, hillwash and blown sand deposits at Brean Down, Somerset, England (Bell, 1990, fig. 32); b) Two major episodes of hillwash erosion within the interior Durrington Walls henge, (C. French); c) Cumulative loessic soil erosion and palaeosol formation at Erd in the Benta valley, central Hungary (C. French); d) Two phases of soil development in post-Neolithic hillwash deposits at Bet al-Kowmani in the Dhamar highlands of Yemen (C. French)

The amount and intensity of vegetative growth has a considerable effect on the susceptibility of soil to erosion (Morgan 1979). Much depends on the height and continuity and density of the canopy and ground/root cover. Forest and dense grass cover are more or less equally efficient at reducing erosion. Vegetation intercepts rainfall and reduces the velocity of both run-off and wind erosion. For example, mean annual soil loss on bare ground can be reduced over 100-fold by dense grass cover, from 4.6 kg per m^2 to 0.04 kg per m^2 (Morgan 1979), and overland flow is much reduced to 10–30% on vegetated slopes (Kirkby 1969b). In contrast, the conversion of forest to arable land may drastically increase soil erosion from almost none to 200 kg per m^2 per year (Wolman 1967). Thus vegetation cover is the critical preventative factor in controlling soil erosion on slopes.

All of these influences must be borne in mind when describing and interpreting hillwash or colluvial and alluvial or overbank flood deposits in the field, as well as the erosion and truncation of soils, and the filling of archaeological cut features.

Several other factors influence archaeological and environmental preservation. These include ploughing, the water regime, the pH status of the soil, soil water and groundwater, and any sealing effects by upstanding monuments such as barrow mounds or banks accompanying ditches of field systems for example, to say nothing of longer-term climate change and modern urban development.

Ploughing alters both soils and archaeological artefacts and features. It breaks down soil structure and can limit its further development. It can cause homogenisation of the topsoil and often the upper or tertiary fills of shallowly buried archaeological features. These processes contribute to the erosion and even truncation of archaeological features under thin soils (Reynolds 1979; Hinchliffe and Schadla-Hall 1980), and the movement of artefacts both up and down and from side to side by anywhere from *c*. 30 cm to 70 cm (Armour-Chelu and Andrews 1994; Boismier 1997; Haselgrove *et al.* 1985). The activity of the soil faunal is also greatly increased, and can lead to much mixing of fabrics and horizons of soils as well as structural change from say blocky peds to a finely aggregated or pellety excremental fabric. In some cases this aids the development and longevity of some soil types such as rendzinas (or thin, poorly developed calcareous A/C soils) on chalk/limestone geology (Kooistra and Pulleman 2010; Macphail and Cruise 1996), but not usually. Also, arable farming practices can artificially enhance the amount of organic matter and phosphates by the ploughing-in of crop stubble and the addition of manure and fertilisers. These factors may distort the bio-chemical and soil micromorphological records. Moreover farming practices may aid soil water percolation, increase the oxygen status of the soil and stimulate micro-biological activity. All of these factors are generally detrimental from our perspective as they may, for example, encourage the destruction of molluscan and palaeo-botanical evidence in archaeological deposits within reach of the plough and out of reach of waterlogged and undisturbed conditions further down-profile, and cause soil mixing and homogenisation.

The nature of the water regime on a landscape or archaeological site plays a major role in determining the preservation of archaeological and environmental evidence. Every site/landscape is different and its preservational context must be assessed individually. Unfortunately in our modern world, most places are characterised by the

deliberate control of river flow and water levels as well as groundwater and aquifer heights. In particular, the proximity of the groundwater and its geo-chemical and water quality characteristics must be understood, as well as how acidic or calcareous the soil water system is, and how aerated it is with oxygen. There are many research papers on measuring the effects of waterlogging on the preservation of organic remains in archaeological deposits (Caple 1993; Caple and Dungworth 1997; Caple *et al*. 1997; Coles 1995; Chapman and Cheetham 2002; Holden *et al*. 2006; Lillie 2007; Lillie and Ellis 2007), but each site in its landscape must be treated as a separate entity that may not follow 'the rules' of preservation as gleaned from these studies and standard hydrological approaches (Ward and Robinson 1990). This means that every site/landscape must be assessed to determine its preservational environment and baises. Data that must be gathered include seasonal and annual rainfall, evapo-transpiration and groundwater variation, the nature of the geo-chemical environment with measurements for pH, conductivity, redox, dissolved oxygen and groundwater quality (*ibid.*; Chapman and Kimstach 1992; Caple and Dungworth 1997). There are some good examples from the East Anglian fens (French and Taylor 1985; French 2009a), at Flag Fen (Lillie 2007; Lillie and Cheetham 2002) and at Sutton Common in Yorkshire (Van der Noort *et al*. 2001; Lillie 2007). Essentially the key to long-term good preservation is air exclusion or anaeorobic conditions since the time of deposition. These conditions are generally signaled by low (and negative) redox values, low proportions of dissolved oxygen, low conductivity values and strongly gleyed soil/sediment conditions. Fluctuating groundwater tables are 'bad news' when it comes to the long-term preservation of organic remains, and more recent dewatering trends associated with agricultural intensification and sand/gravel/clay extraction as well as urban expansion have an ever-present detrimental effect on the continuing preservation of buried palaeo-environmental remains. One need look no further than the peatlands of East Anglia where lowered groundwater levels over the past few hundred years have caused the destruction of huge areas of peat, and peat shrinkage of up to 4 m (French 2003, 12–13; Coles 1995), or the Haryana arable 'basket' of north-west India where groundwater tables that were <10 m below ground surface about a decade ago are anything up to 50 m below ground surface now through a combination of water abstraction for irrigation and the lack of natural monsoon-related flooding events (French *et al*. 2014).

The pH status of the soil, feature fill, soil water complex and groundwater is another essential preservation factor measure in soils and sediments. Obviously much depends on the nature of the underlying geology and from which the groundwater emanates. The key is having a high groundwater table year-round and this not being subject to seasonal fluctuations so as to exclude air, rather than so much whether it is calcareous, neutral or acidic. Other mitigating factors can be the texture of the soil or feature fill, so for example a relatively non-porous silty clay is much more advantageous than a permeable medium sand or chalk rubble. Similarly the nature of burial may be very important, for example whether the archaeological feature/horizon/buried soil is covered by a dense mound of turves or a plough headland, or sealed by a clay or plaster floor. Proximity to ploughsoils that have been heavily fertilised in the past may change the base status of both the soil and soil water complex. For example at Star Carr in the Vale of Pickering, Yorkshire, the peat deposits burying the Mesolithic

wooden platform and bone artefacts are now highly desiccated and highly acidified as a result of a combination of modern drainage, ploughing and bacterial attack on the peat (Boreham *et al.* 2011; Milner *et al*. 2011).

Formulating research designs

In any archaeological project, whether it is a rescue excavation in advance of some kind of development or a research survey and/or excavation project on grant funding, there are still a number of basic approaches which should be followed as a matter of course, both in situating and designing the project. First, your ***research question*** or questions must be devised. It often helps at the outset to know what are the ***research priorities*** for your chosen study area. In some parts of the world, such as England, there are a number of documents outlining research directions, priorities and gaps in our knowledge, done both at a national scale by English Heritage (e.g. Olivier 1996), and regionally across the country (e.g. for East Anglia: Glazebrook 1997; Medleycott 2011). This makes it much easier to see what major research agendas, priorities and/or gaps in knowledge may be addressed by your proposed project. Obviously, for many parts of the world, these types of documents do not exist or only partly do so, and to be at the same level of knowledge and question setting requires a much wider archaeological knowledge of the region and a good grasp of what archaeological and palaeo-environmental work has already been done. This is where local and professional knowledge from your hosts/collaborators on the ground is absolutely essential to find out. In other instances, especially for specific grant applications, it may be necessary to tailor the archaeological project design to other agendas, such as the impacts of urban development or long-/short-term climate change, or issues of agricultural sustainability. Thus it is essential to situate your project design to address research priorities for the chosen study area, available archaeological sites or landscapes, and/or appropriate time periods, and/or differing data-gathering exercises or research agendas.

Then you must begin to address a variety of other related design criteria. These include: what scales of approach will be used?, what kind of resolution is required?, what techniques will be best employed?, what scale of sampling is appropriate?, what specialists do you need on your team?, and who is the work intended for – commercial, academic, research body, general public or some combination of these? In addition, are there concomitant issues relating to any present day social responsibilities, such as any feedback into present day land management and policy, implications for and/or corroboration of climate change debates, and/or relevance to site and landscape survival, and heritage resource and preservation issues?

Then the appropriate classes of data that may be available need to be considered. Which sets of evidence are potentially the most appropriate for tackling your research problem and which are the most data-rich and reliable? In short, how do you tailor your evidence gathering to the question/problem at hand? What are the available sources of archaeological and environmental evidence? These should include existing soil and geological maps, sites and monuments records, published and unpublished archaeological reports, aerial photographs and more recently perhaps lidar surveys

(Fig. 10), and any robust studies of past and present environmental conditions, both locally and in the immediate region. What new datasets are being procured through other rescue and research projects in your study area, how relevant and reliable are they, and what scale of interpretation can be placed on them? Is the project time period dependent or defined in some other way, is it more focused on a wider region or some subset of the region, or is it dependent on the type or the availability of particular kinds or groupings of sites? Integral to all these criteria is the scale of proposed work: is it to be landscape survey or some kind of focused excavation(s), on a large scale or small scale, or is it more test excavation of many sites across a landscape or an archaeological field survey, or some phased combination of these?

Throughout there are a number of other practicalities that need to be sorted out as part of the thinking behind the research design, and to make it a good research proposal. What are the appropriate methodological approaches and accordingly who is on the project team? This criteria governs the specialisms needed to a large extent, and indeed much of the future costs of the project. The team members chosen need to have a demonstrable record of their expertise and a timely publication record. Do you have local and national-based collaborators and hosts on-board and on the ground willing to help with all logistical aspects of conducting your fieldwork successfully? Do you have your access permissions sorted out well in advance and any fieldwork permits in-hand with the land-owner and the local/national archaeological authorities? What are the costs and time implications for each stage of the project? How will project planning

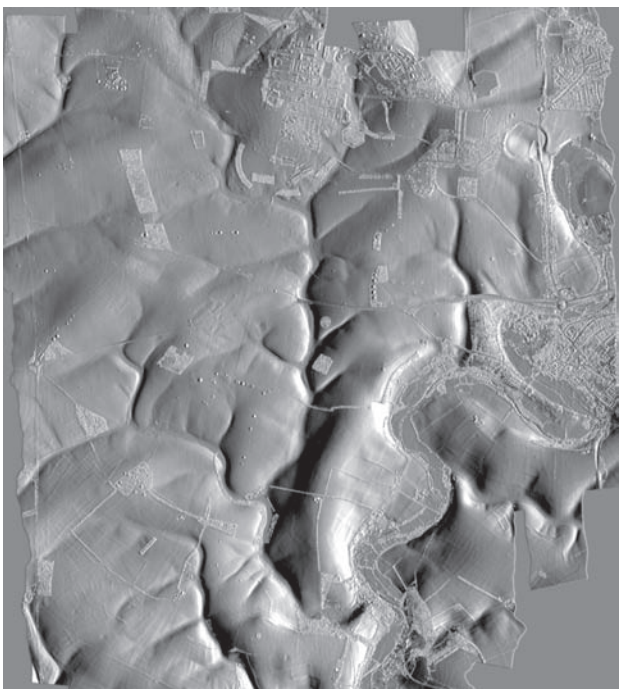


Fig. 10. Lidar image of the Stonehenge and Durrington Avon area (with permission of C. Shell)

and monitoring be carried out? Who is responsible for the collation of all reports and overall interpretation? What is the planned analytical phase as well as the publication schedule and associated costs? – remembering that this usually takes twice as long as any fieldwork and usually greater than twice the cost to do well. What other outputs will result from the project, such as research seminars or dedicated conferences, public dissemination events and/or web-sites, and what are their associated costs? Thus, the project design has to show why a particular approach is to be adopted. It must be not just imaginative and innovative but also feasible, and it must have clearly identified questions, a timetable, milestones or monitoring points, a precise, itemised but flexible budget, and significant but achievable publishable and outreach outcomes.

In terms of thinking through the stages of the project, it is often good practice to have a number of linked parts to the project, each building on each other. No landscape can be divorced from people and their activities, and every site is a part of its broader landscape and settlement contexts. So to begin to talk about human impacts on any landscape you need to first understand the baseline data of wherever you are in the world. This can be achieved for example by starting with some kind of initial evaluation which assesses the existing relevant archaeological, historical, geological, ecological and palaeo-environmental records, before going on to plan and undertake a second stage assessment which involves some initial intervention on the ground. This could perhaps involve a systematic fieldwalking sample of the several identified landscape zones in your study area, rapid on-foot geoarchaeological survey of the river course and its floodplain and/or tributary streams, and a systematic borehole survey transect across the watershed and valley with initial stratigraphic recording of existing sections and those opportunistically exposed in river cuts or well profiles for example, or some combination of these approaches. At this or a later stage, test pitting or trenching may well be necessary to ascertain accurate soil/subsoil/groundwater preservation parameters and for systematic sampling. A selection of these techniques should allow an initial attempt at determining preservation of both sites, the range of artefact types present, and classes of palaeo-environmental data that may be surviving in the landscape system under investigation. The latter exercise would entail taking soil/sediment samples to assess the presence of pollen, insect, macro-botanical preservation and the geo-chemical burial environment, as well as the survival of palaeosols for example, and whether any waterlogged conditions prevail in particular parts of the landscape. Then on the basis of this first and second stage reconnaissance data, one should be able to plan the full field programme and full extent of analytical techniques necessary to address your research question.

Gathering together the geological and present soil records, land classification data, the hydrological context, rainfall and drainage pattern, and the known settlement and archaeological records, are all essential first steps. Much can usually be gleaned from existing maps and curated historical and archaeological records, aerial photographs (Palmer 1996; Wilson 2000), consulting the local/regional historic environment public records, and environmental/meteorological agency records and reports. Sometimes it is possible to refine these records further by obtaining or commissioning new lidar aerial photography (Fig. 10) (Bewley *et al.* 2005), which will give you much better topographical information and often additional archaeological data. For example this

may allow you to see areas of thicker soils or erosion, former palaeo-channels, ephemeral field system boundaries, and even inter-relationships of superimposed archaeological and/or natural features in the landscape. These, along with the topographical maps of your study area provide the initial layer (or digital elevation model or DEM) of your Geographical Information System (or GIS) (Fig. 11) (Burrough 1986; Connolly and Lake 2006; Kvamme 1993), essentially creating your baseline for any future exercises in modeling of various hypotheses of landscape change through time (French 2010b; Barton *et al.* 2010).

To tackle the above assessment stage, it is often advantageous to utilise particular sampling strategies, such as systematic versus judgmental, or the use of transects or blanket coverage, or extensive but brief assessment versus intensive and detailed survey and analyses. For example, the Welland Valley project used a series of systematic transects to examine a 10% sample of every kilometre north–south strip of land along a 20 km stretch of Cambridgeshire fen-edge river valley landscape (Fig. 12), followed up by targeted rescue excavations of large areas of identified prehistoric sites consequent on gravel extraction with associated specialist analyses of pollen, insects and palaeosols (see below) (Pryor and French 1985; French and Pryor 2005). In the 10 km stretch from the head of the Fiume di Troina valley of north-central Sicily, a similar approach was used with systematic fieldwalking of a 100 m wide swathe in every kilometre (or 10%) across the hillsides and valley bottom, 100% geoarchaeological and pedestrian survey of the river valley bottom and floodplain area, and targeted augering and sample excavations of identified Neolithic sites (Fig. 13) (Ayala 2004; Ayala and French 2005; Malone and Stoddart 2000). In contrast around Aksum in highland northern Ethiopia, an extensive geoarchaeological survey concentrated on the colluvial and alluvial erosion records of two inter-related valley systems and a high hinterland using pedestrian survey of the river and tributary valleys, opportunistic and targeted recording and sampling of eroded valley, terrace and well sections (Fig. 14) (French *et al*. 2009a; Sulas *et al*. 2009).

A combined archaeological and geoarchaeological survey project in the upper Allen valley of Dorset, initially used systematic augering transects located at about 500m intervals across the valley over a reach distance of some 10 km in combination with aerial mapping of the archaeological record and the colluvial/alluvial drift geology (Figs 15, 25 and 26) (French *et al*. 2007). This was followed by judgementally chosen test excavations of 20 Neolithic, Bronze and Iron Age sites that were used to provide on- and off-site archaeological, soils, pollen and molluscan data in all landscape zones in this part of Cranborne Chase (see below and Fig. 27) (French *et al*. 2000; 2003; 2007). In contrast, the dyke survey of the peat fens of north-western Cambridgeshire systematically surveyed whole exposed lengths of randomly available dykes that were cleaned every 5–7 years, and recorded and sampled their stratigraphic record, palaeosols and archaeological artefacts, features and sites to determine long-term Holocene landscape change (Fig. 16) (French and Pryor 1993). Similarly the geoarchaeological and palynological investigations of the middle reach of the Rio Puerco river system in central New Mexico systematically surveyed whole exposed stretches of the main river and tributary arroyos which enabled long-term landscape change to be identified with its implications for climatic change (see below) (French *et al*. 2009b).

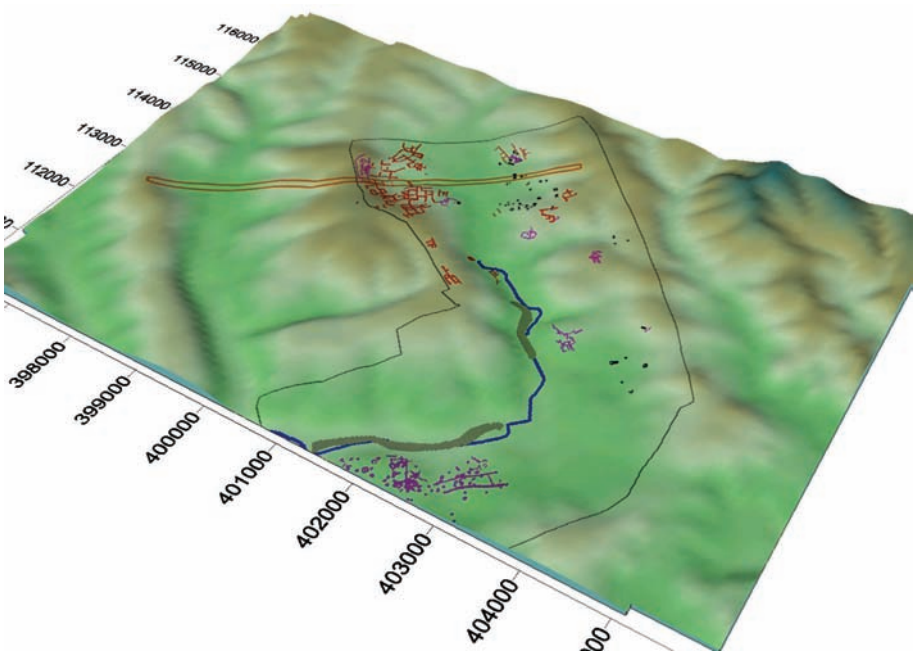


Fig. 11. A digital elevation model of the prehistoric sites in the upper Allen valley of Cranborne Chase, Dorset, England (C. Begg)

To reach the next level of data retrieval, or conduct a second stage assessment, some kinds of sub-surface testing or ground-truthing are really needed. To begin with these may include systematic and gridded fieldwalking for artefact retrieval, and targeted geophysical prospection, especially where settlement features are suspected on the basis of fieldwalking survey. At the same time as this background evaluation, you should also be assessing the potential preservation environments that exist in your study area. This will inform you of potentially what sources of data may be available, and therefore alert you to what types of specialist you may need, and their time and budgetary requirements. This may involve hand or power augering of boreholes, test pits or trial trenching to get a handle on the stratigraphic sequences in your landscape, the presence/absence of deposits such as alluvium and colluvium, as well as buried soils and archaeological survival. These small ground interventions should be conducted as systematically as possible, say at 20 m/50 m/100 m intervals, in transects, with each topographical zone in your landscape (i.e. floodplain, terrace, lower slope, upper slope) receiving equal treatment, and a consistent percentage of the landscape subjected to the same methodological suite of techniques (i.e. at least 10% by area). Other prospection methods may be used at this stage such as geophysical survey to delimit and define sites, whether settlement, burial or communal/ceremonial (English Heritage 2008). It is very important to determine how sacrosanct the archaeological deposits are in terms of their physical preservation, or not as the case may be, as this will largely determine the

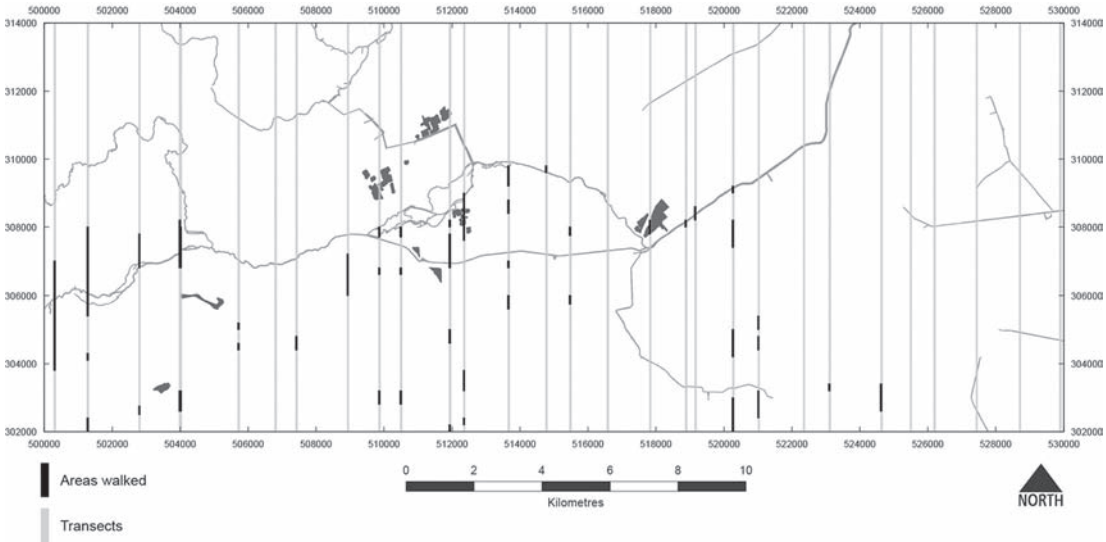


Fig. 12. Random 10% corridor transect sampling every kilometre of the lower Welland valley, Cambridgeshire, England (C. French)

Fig. 13. The archaeological survey of the Fiume de Troina valley, Sicily and the 10% geoarchaeological survey transects (from Ayala and French 2005, fig. 2)

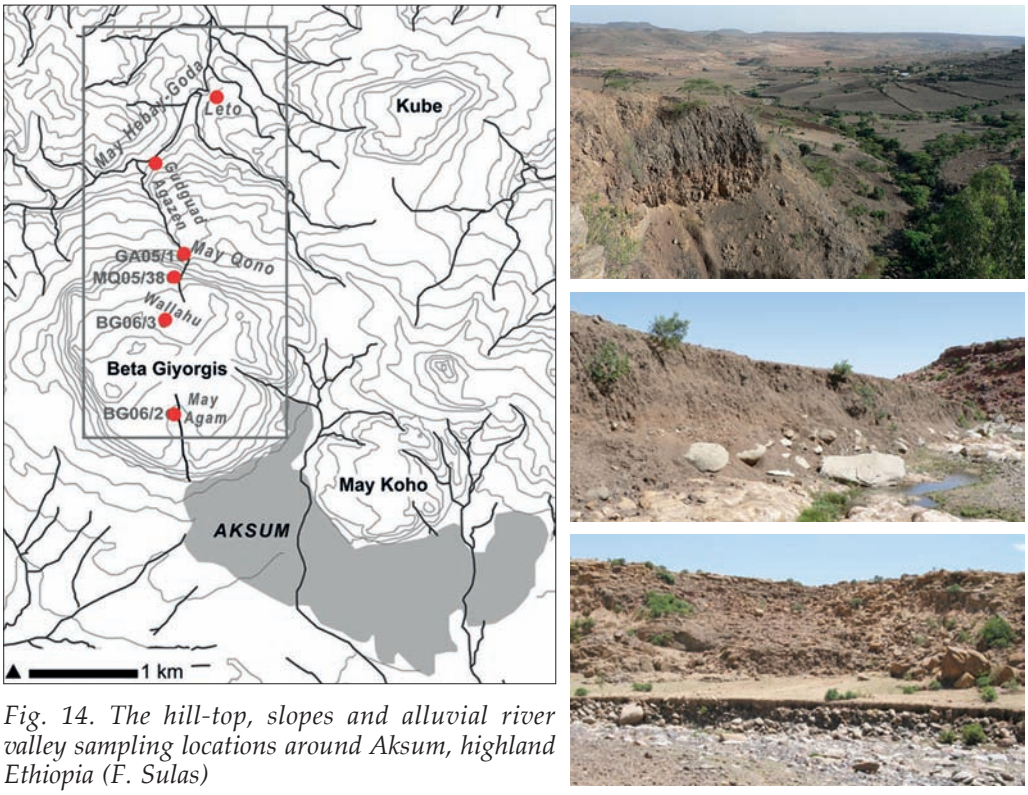


Fig. 14. The hill-top, slopes and alluvial river valley sampling locations around Aksum, highland Ethiopia (F. Sulas)

Fig. 15. Hand augering through a Bronze Age barrow ditch at Over, Cambridgeshire, England (left), and using a Russian auger to sample peat deposits in a palaeo-channel in the Rio Chico, Pali Aike, Chile (right) (C. French)

Fig. 16. Dyke survey of the Flag Fen basin, east of Peterborough, Cambridgeshire, showing the gravels, palaeosol (pale horizontal zone below staff) and overlying peat and alluvial sequence (C. French)

Fig. 17. Systematic gridded test pitting of the buried soil on the Godwin Ridge, Over Quarry, Cambridgeshire (D. Webb, Cambridge Archaeological Unit)

level of intensity and types of analyses required of the next phases of fieldwork. If test pits are used, a similar volume of soil from each soil/sediment horizon should be sieved (wet or dry as appropriate) for artefact retrieval. If *in situ* buried archaeology or buried soils are encountered, these should always be sampled for soil micromorphological, geo-chemical (i.e. phosphates and multi-element) and magnetic susceptibility analyses, preferably by a recognised specialist, and large bulk samples taken for macro-botanical and phytolith assessment and analysis. If waterlogged deposits, peats, fine-grained palaeo-channel fills or palaeosols are discovered, particularly in floodplain and floodplain margin situations, either columns or systematic sets of small bulk samples should be taken by depth for palynological analysis and possibly diatom analysis as well. Anywhere that good organic and/or charred remains are found above/below/at major horizon boundary changes, these should be kept for potential radiocarbon assay. If there are no organic remains suitable for radiocarbon dating, then section profiles should be sampled for optically stimulated luminescence (OSL) dating as long as there are old land surfaces present and a sufficient quartz sand component in the soil/sediment (Aitken 1985; Grun 2001; Wintle and Murray 2006).

A third phase, or some level of excavation of major sites of importance may well follow this second assessment phase, but only after thorough analysis and reporting on the data retrieved to date. This will allow the best information return to follow. But from a landscape interrogation point of view, targeted sample excavation may be more appropriate than large set-piece excavations. For example, the off-platform site stratigraphic and palynological studies at Flag Fen were conducted via small machine-dug trial trenches excavated at set intervals across the northern part of the Flag Fen basin from the Fengate shore to Northey 'island' (French 2001; Pryor 2001; Scaife 2001). Where a complete buried landscape is revealed with an intact buried soil, it is often necessary to treat this as a whole new landscape with systematic gridded field-walking, geophysical survey, possibly some geo-chemical testing and test pit excavation for artefact recovery and palaeo-environmental and soil sampling as at Over in Cambridgeshire (Fig. 17). In contrast in the upper Allen valley of Cranborne Chase, individual upstanding monuments of different ages and locations in the different landscape zones of the chalk downland were deliberately targeted with sample trenches to obtain buried soil and molluscan data from the ditches and beneath banks or mounds (French *et al*. 2007). Other valley-wide approaches are more likely to involve some kind of sampling approach across the landscape, as for example was done during the Troina valley project (Fig. 13) (Ayala 2004; Ayala and French 2005).

As multiple sets of descriptive data are regularly obtained from these types of archaeological landscape project, one of the best ways to interrogate and manipulate these datasets is through GIS (Geographic Information System) modeling applications (Lock and Stancic 1995; Connolly and Lake 2006). This is rarely as easy as is often made out, and it necessitates selecting just a few data-rich variables to do best. These can be relatively simplistic or crude, but in practice usually give the archaeologist some possible interpretative scenarios with which to either visualise and/or hypothesis test the available data.

For example, Ayala (Ayala and French 2005) used the universal soil loss equation (or USLE; soil loss and erodability, rainfall, slope and vegetation cover) (Wischmeier and

Smith 1978) in a GIS to examine the potential effects of Roman farmstead expansion on the erosion system near Troina in Sicily. Here the model's results indicated greater clearance for winter pasture could have been a driving force behind the intensifying soil erosion (Figs 18 and 19). Other developments using this approach are exemplified by Favis-Mortlock *et al*. (1997) creating predictive models of eroded loess and hillwash distributions on the South Downs of south-eastern England, and by Barton *et al*. (2010) using the USLE with a geographic analysis and support system (GRASS) to model Neolithic subsistence practices of the Wadi Ziqlab in northern Jordan, and suggested two alternative landscape scenarios – a pastoral economy predominating over arable agriculture and disaggregation from village to small hamlet.

Samarsundera (2007) used dynamic spatial models to test how a 100 hectare square area of Wyke Down landscape of Cranborne Chase changed using pollen data, ecological succession scenarios and livestock grazing behaviour, concluding that intensive grazing could have caused and sustained marked forest recession observed in the earlier Neolithic period. The GIS model generated suggested that relatively dense numbers of livestock would have been needed in the later Neolithic to maintain that large degree of openness in the landscape with herd numbers of 20–250 per 100 hectares (Fig. 20) (French 2010b), with the additional consequence that human population numbers supported by this livelihood could be much larger than hitherto suggested.
I will now turn to the discussion to the investigation of wetland, dryland and temperate landscapes from an integrated archaeological and geoarchaeological perspective.

Investigating wetland landscapes

Wetland landscapes usually present comprehensive and informative archaeological and palaeo-environmental data preservation. The investigation of wetland environments usually allows the creation of long-term landscape developmental histories and often gives very specific evidence of the human role in shaping landscapes over time. Generally, the excellent preservation of buried soils and associated plant micro-fossil (i.e. pollen, insects, diatoms) and macro-fossil (i.e. wood, charcoal, molluscs, bone) data with good dating prospects presents the opportunity to develop well-evidenced sequences of landscape and land-use change. But, these strong plus points are often demoted in information return by a variety of post-depositional effects such as flood- and groundwater-derived processes and leaching and acidification. These may denude and/or skew the soil formation signatures indicative of past land-use and/or cause differential destruction of soil micro-fabrics, to say nothing about the detrimental effects of modern drainage on many former wetland systems and the associated sites and organic remains.

Not that long ago a common palaeo-environmental approach to the investigation of wetland landscapes was to locate the deepest and wettest part of the basin or peat deposit with the longest stratigraphic record and conduct a well-dated pollen analysis. This would reflect a mosaic of palaeo-vegetational development through time indicative of the wider region, sub-regional hinterland and the developing wetland basin itself. The obvious implication of this approach is that these palaeo-environmental sequences

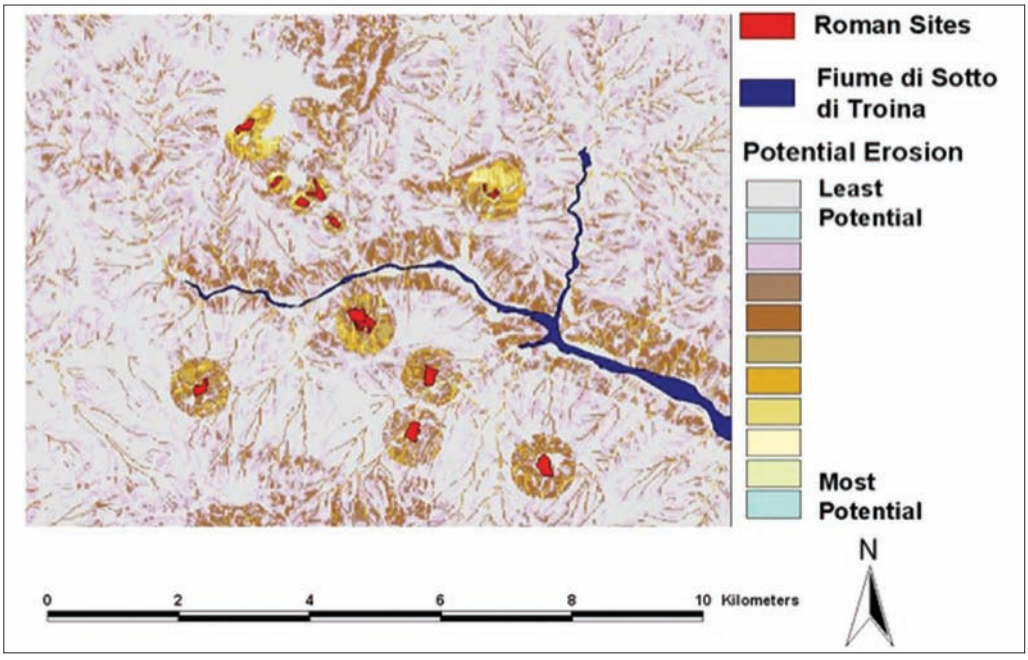


Fig. 18. Modeled potential erosion for mixed subsistence farming being undertaken in the Troina river valley in north-central Sicily during the Roman period (from Ayala and French 2005, fig. 7)

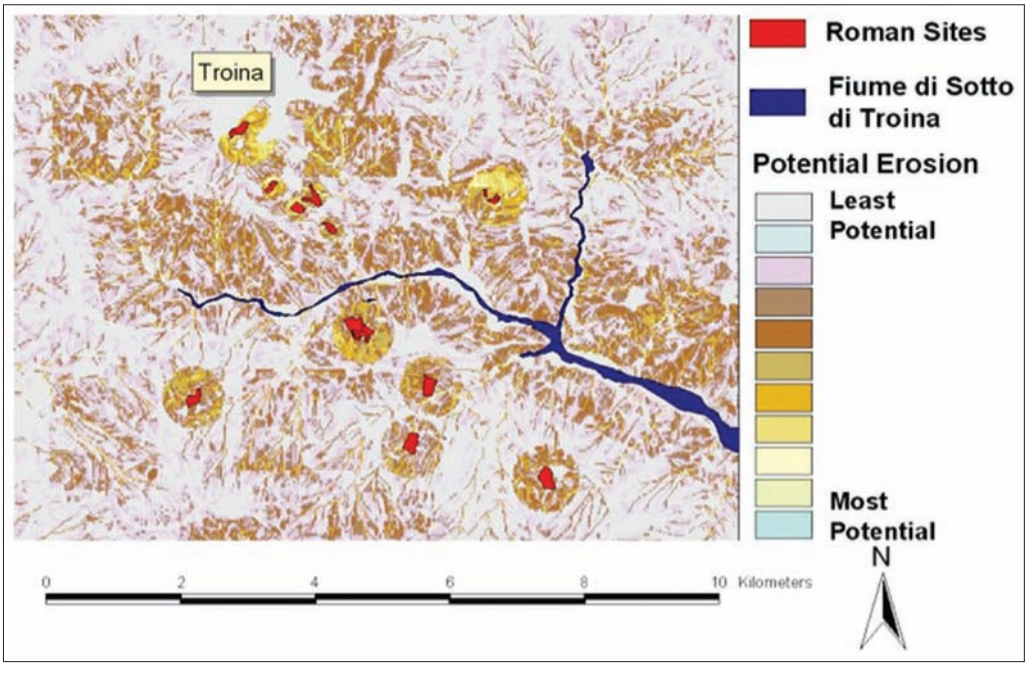


Fig. 19. Modeled potential erosion for intensive pastoralism being undertaken in the Troina river valley during the Roman period (from Ayala and French 2005, fig. 8)

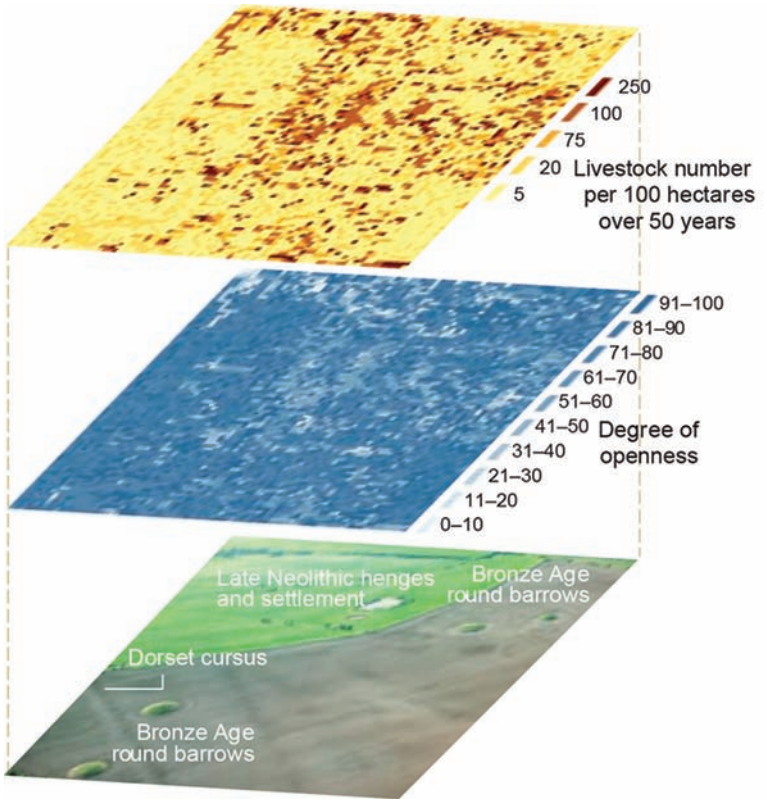


Fig. 20. A dynamic archaeological-palaeo-environmental GIS-based simulation model: an oblique aerial view of the prehistoric sites of the Wyke Down area of Cranborne Chase, (lower), overlain by a model of arboreal cover in the earlier Neolithic based on pollen data representing 64% open ground (middle) with a superimposed model of associated grazing intensity expressed as livestock numbers over a 50 year period per 100 ha required to keep that landscape open (upper) (D. Redhouse after E. Samarasundera 2007)

are not representative of where people were actually living. Rather people were living on the margins of the wetland basin, usually over which wetland deposits subsequently encroached at certain time periods. Sure, human impacts were often reflected in the pollen diagram and the stratigraphic sequence, but how well related were these to the archaeological story on the immediate wetland/dryland margin, and how had the formation of the waterlogged burial environment affected this record? Indeed, research into the spatial range and deposition of pollen rain (e.g. Barber 1988; Bradshaw 1981; Edwards 1993) has suggested that pollen sampling positions need to be within a few hundred metres to not more than 1–2 km distant from the dryland edge to be properly relevant to the human story of landscape development.

Consequently, it is much better to develop a transect sampling approach from deepest/wettest part of the basin across the damp margins to dryland/higher

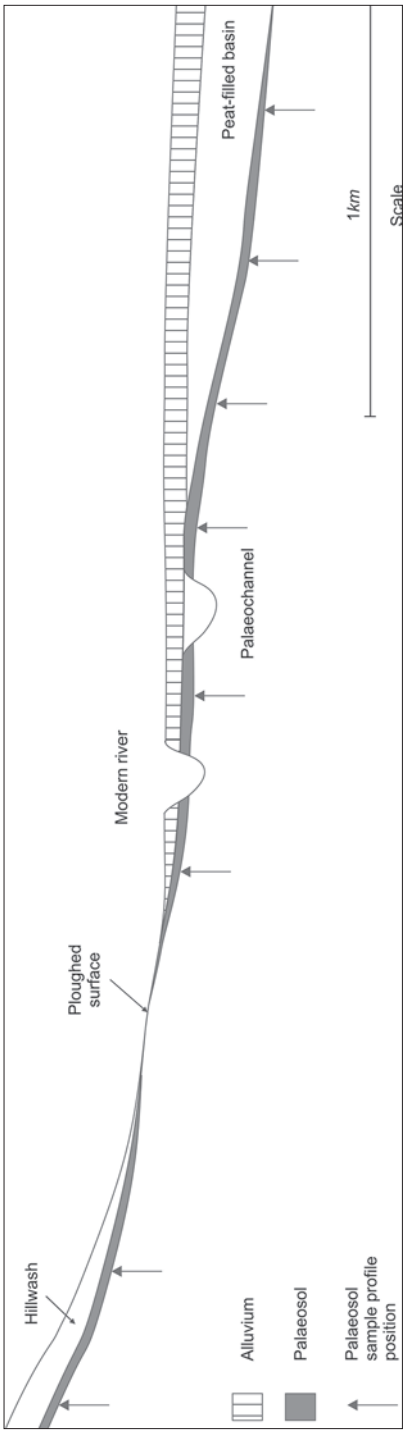


Fig. 21. Schematic profile of a basin and its buried soils (D. Redhouse after C. French)

ground to address this problem (Fig. 21). For example, this could entail a borehole transect survey across the basin from the dryland, say at 50 m intervals, followed up by machine trenching every 100 m/200 m for sampling loci. Ideally, the pollen and adjacent buried soil records should be compared from suitable natural (i.e. palaeo-channel, buried soil beneath alluvium/peat deposits) and archaeological features on the dryland (i.e. larger pits, wells, buried soils beneath banks) as well as through the full stratigraphic basin-buried soils sequence on the wetland/dryland margin at *c*. 100–200 m distant, and again at *c*. 500 m and 1 km intervals within the adjacent basin.

Moreover, sample intervals within each stratigraphic column should be as intensive as possible. For pollen this is at intervals of at least 1 cm every 4 cm, with AMS (accelerated mass spectroscopy) radiocarbon dating of the pollen zonation sequence revealed, as well as small bulk sampling to determine geo-chemical inputs in the basin that may reflect soil disruption and land use activities on the adjacent dry land (Mackereth 1965; Willis *et al*. 1997; 1998). These studies should then be related to the formation of the waterlogged burial environment (Caple and Dungworth 1997) and the buried palaeosol history within the basin itself and on its margins using micromorphological techniques (French 2003, 47ff.), as well as the exploited plant macro-fossil and faunal records from archaeological sites in the immediate basin and its surroundings.

In terms of the buried soil record, it is essential to use the topographical situation of the basin or valley to locate, sample and create a palaeo-catena or a sequence of buried soils on the same geological substrate dependent on relief and drainage characteristics. This can be done using Dalrymple's nine-unit model to visualise the zones of erosion and accumulation in

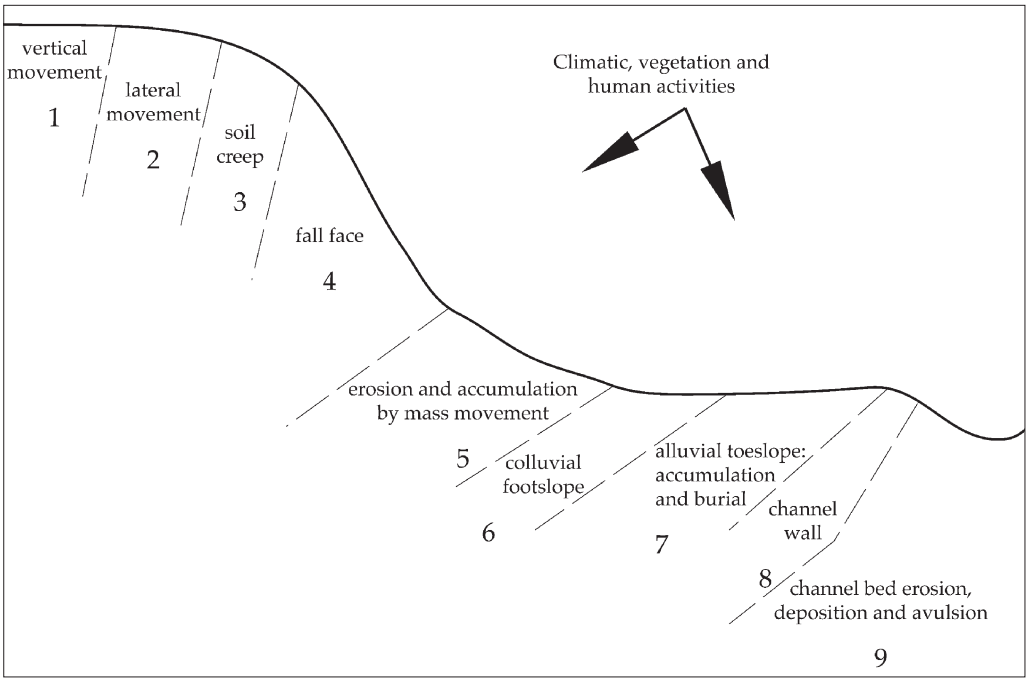


Fig. 22. The nine-unit hill-slope model (D. Redhouse after Dalrymple et al. *1968)*

the landscape (Dalrymple *et al.* 1968) (Fig. 22). The use of thin section micromorphology is an ideal technique for the analysis and interpretation of buried soil sequences as it gives detailed process sequencing information on the development of that landscape, both from the perspectives of natural processes and human modifications (Courty *et al*. 1989; Stoops 2003). Slow burial of former dry land surfaces through gradual encroachment of later deposits such as peat and alluvium, rather than experiencing rapid and severe erosive forces, means that the soil record developed on the natural solid/drift geology is generally well preserved and often intact. Obviously the soil record much depends on site specific geological, hydrological, climatological and vegetational parameters as well as the wider trajectories of landscape development and human land-use (Kirkby *et al*. 1996), and the particular circumstances of burial (Fig. 23). But, the two key inter-relational aspects for the palaeo-catena are having the same geological substrate and hydrological regime, and knowing the date by which a soil or old land surface becomes buried (Kwan and Lee 2004). In particular, this is where soils buried by individual upstanding monuments such as barrow mounds or field or enclosure banks are a bonus. The ideal situation is to judgementally target as many well preserved buried soils on the dryland margin of the archaeological site/landscape as possible, and which give the broadest possible chronological and spatial spread of sample loci. For example, in a British context this might include sampling beneath a Neolithic long barrow or enclosure bank, a Bronze Age barrow or field system bank, and Iron Age or Romano-British enclosure bank, and a medieval plough lynchet or field bank. If as many of these

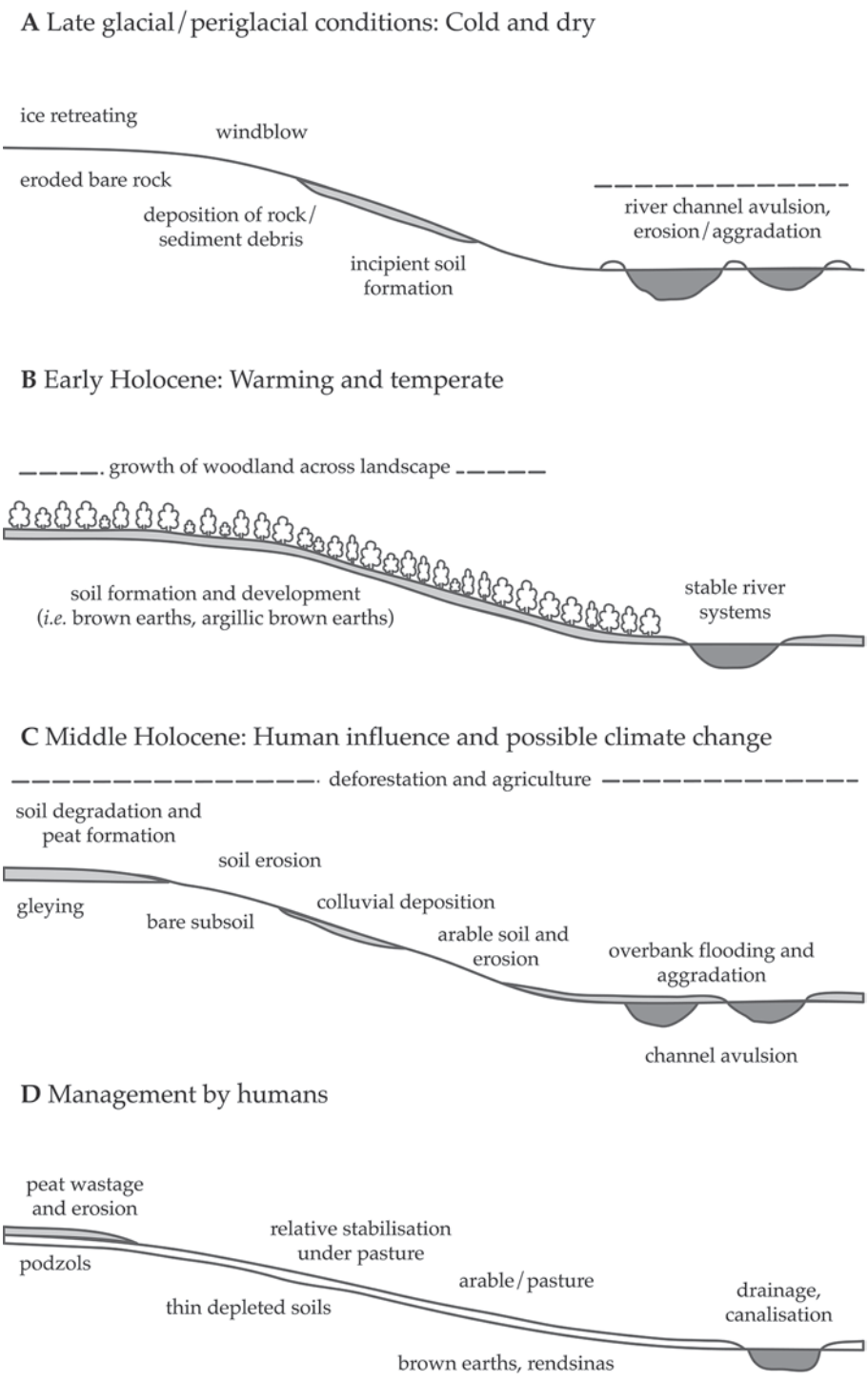


Fig. 23. Schematic palaeo-catena models for the development of soils in the Holocene of southern England (C. French)

types of upstanding features could be targeted in as many topographical and geological zones as possible in the same valley system, such as on the higher terraces, first terrace, floodplain edge and river's edge type of situations, all the better. Then it is possible to reliably discern the sequence of soil development through time in a broad area of landscape, as well as infer different land-use circumstances directly related to past human activities. In addition, some of the upstanding archaeological features would have been subsequently buried by flood-derived deposits on the dryland/wetland margin or beneath hillwash deposits at the base of slope (see Figs 6, 7 and 8), thus insuring a relative absence of destructive and mixing processes through later land-use practices, as well as causing waterlogging leading to better preservation of the organic component of these soils, and perhaps even preserving contemporary palynological and macro-botanical records in the old land surface. As the buried landscape dips beneath the developing basin deposits, buried soils should still be found (Fig. 21). But there tends to be a diminishing scale in terms of soil development and preserved landscape/land-use signature features becoming less and less well developed in the palaeosols with depth into the basin, and as more and more post-depositional distortion occurs through processes such as soil mixing, wetting/drying, leaching and lateral flushing.

In addition to the palaeosol and palynological data, it is important to conduct a systematic palaeo-topographical and deposit mapping survey of the whole basin area. This can be aided through aerial photography and especially the use of lidar which shows the subtlest variations in topography (Fig. 10), accompanied by a systematic borehole survey to allow the basin's deposit sequence to be mapped by depth and lateral extent and visualised in a GIS (Connolly and Lake 2006) (Fig. 24, i.e. at Over, Cambridgeshire). This survey should also reveal any presence of buried palaeo-channels, embayments, and/or palaeo-lakes within the basin. In turn, this allows both archaeologists and palaeo-environmentalists to situate their sampling transects to target these specific buried landscape features, which should contain much more complete palaeo-vegetational records, and predict possible locations of archaeological sites. Only then can one build well-dated histories reflective of long-term sequences of landscape change and the human activities contained within that record across the whole basin and its dryland margins.

Soils found in wetlands have enormous information potential for deciphering past landscape histories, but their analysis and interpretation need to be approached with caution, whatever their circumstances. Individual hydrological circumstances control sediment deposition, soil formation, the groundwater table and the preservational context, but saturation almost always leads to some alteration and/or destruction of the soil record. Consequently this may make the interpretation of once dryland soils, either flooded and/or buried by later wetland deposits and/or transformed through changing natural conditions or human activities, much more problematic. Moreover, the actual nature of the inundation or wetting process may distort some or all of the physical preservation of the soil/palaeosol. Truncation from fast flowing floodwater, storms and wind/wave action are obvious candidates, but often it is more subtle changes which lead to the depletion, alteration and/or removal of soil fabrics and micro-fabrics, the obscuring and blurring of horizon boundaries and distinct changes in soil texture and type. Thus observation and recording in the field are more difficult,

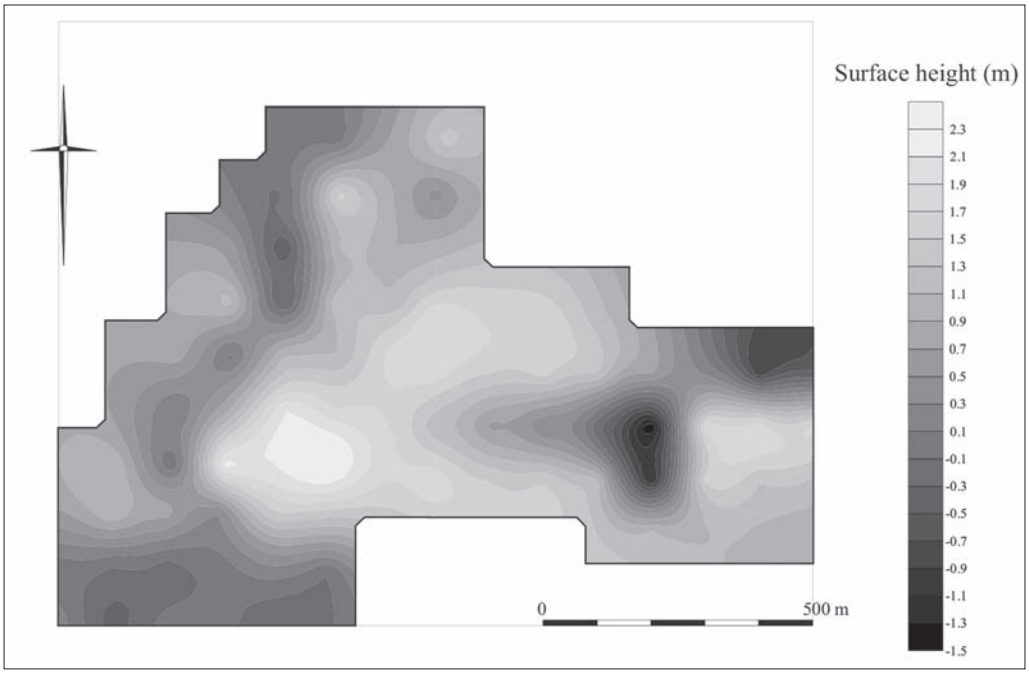


Fig. 24. Buried terrain model of the Southern Barrow Group area in the lower Great River Ouse at Over Quarry, Cambridgeshire, with the pale grey areas equating with higher parts of the river terrace garvels and the darker grey to black areas with palaeo-channel zones (C. Begg; Cambridge Archaeological Unit)

but make comprehensive soil/sediment analytical work an imperative component for understanding any wetland or buried wetland context. This work should include the use of soil micromorphology, physical and geo-chemical analyses, and the determination of water quality parameters, in combination with an appropriate suite of other palaeo-environmental techniques such as the analyses of pollen, plant remains, molluscs, diatoms and/or foraminifera (Tables 1 and 2). All of these data types require precisely dated stratigraphic control, and only then may models of flooding episodes, floodplain change, shoreline alteration and associated soil changes be advanced which may be correlated with the archaeological record.

Investigating dryland systems

Similar geoarchaeological methods and approaches to those discussed above for wetland systems may be used in any dry land situation, but one must be aware of potentially very different climatic, hydrological, geomorphic and preservational conditions.

Climatic factors are key. In many parts of the world, there is often less than 200–400 mm of rainfall per year. This makes all semi-arid to arid terrains subject to

Table 2: Summary of main sample methods, sizes and applications used in geoarchaeology

Sample method	Sample sizes	Applications
Soil/sediment micromorphology	intact block, up to 14 × 10 × 8 cm	identification of soil types & processes, sequences of land-use, human activities and post-depositional distortions of the archaeological record
pH	small bulk sample, 40 g	acidity-basicity, soil history, preservation indicator for types of artefacts and ecofacts
EC (electrical conductivity)	small bulk sample, 40 g	indicator of preservation conditions
Redox and Dissolved oxygen	small bulk sample, 40 g or known volume of groundwater	indicator of preservation conditions and quality of water in soil system
Magnetic susceptibility	small bulk sample, 40 g	identification of burning, secondary iron formation, weathered surfaces and human activities
Loss-on-ignition	small bulk sample, 40 g	proxy for organic content of soil/sediment, and soil organic formation
Particle size analysis	small bulk sample, 100 g	relative and cumulative frequencies of sand/ silt/clay size components of soil/sediment, understanding soil/ sedimentary sources and processes
Phosphorus (or total phosphate) content	small bulk sample, 40 g	identification of inorganic and organic sources of organic matter and waste matter in soils/sediments, prospection for human settlements and activities, interpretation of deposits and features
Multi-element analysis (ICP-AES or Inductively Coupled Plasma – Atomic Emission Spectroscopy; or Micro-probe)	small bulk sample, 200 g	identification of elemental and heavy metal components of soils/sediments, interpretation of human related activities, prospection for human settlements and activities, interpretation of deposits and features
X-ray fluorescence (XRF)	small bulk sample, 40 g	a non-destructive technique used to identify materials or elemental content
Scanning electron microscopy (SEM)	small bulk sample or intact block	identification of soil/sediment chemical components and clay mineralogy and structures
Mineralogy	small bulk sample, 40 g	identification of minerals composing soil/ sediments and identifying their origins
2-D X-radiography	intact block or column, any size/length	understanding of deposit formation and hiatuses
Bulk density, shear testing and plasticity	intact block or core sample, up to 14 × 10 × 8 cm, of known volume	indicators of degree of saturation to make a soil/sediment mobile and an index of erodability

the development of a weak and sparse surface vegetation, which is consequently very vulnerable to the effects of rainfall (i.e. thunderstorm) events as these bring low percolation and very high run-off (Cooke *et al.* 1993). Vegetational stability is low and very susceptible to minor changes in air temperature and rainfall. Just the difference in the direction of the slope-face controlling the amount of dew in the early morning can create greener or more desert-like conditions. These climatic conditions make soils very prone to rainsplash disruption and mobilisation downslope in mass movement erosive episodes. Irrigation may therefore be necessary to sustain viable agricultural crops and their associated communities, or some means of water and/or food storage, and/or soil conservation measures to increase the chances of the system retaining some resilience to on-going degradation and desertification processes.

High daily and annual temperatures lead to conditions of high evapotranspiration and low humidity. This therefore reduces the usefulness of the rain that does fall or dew that accumulates. In turn this reduces vegetative cover, leading to increased areas of bare ground with even greater susceptibility to soil erosion. High temperatures increase the soil temperature, which in turn increases insect activity. This affects both germination times and vegetation growth types. The rates of physical and chemical weathering of substrates is increased, and often leads to the formation of secondary calcium and iron minerals for example. On the other hand, extreme aridity has a very positive effect on the preservation of organic materials as a consequence of the atmospheric dryness and very low humidity. One need only look at the exquisite preservation of loom-woven natural fabrics in the Samaca basin of the lower Rio Ica valley of southern Peru on many archaeological cemetery burial sites, or the wooden structures and uncharred food remains surviving in 5000+ year old middens on the Pacific coast (Beresford-Jones 2011) (see Fig. 33).

Relief is also very important. Steep slopes often have an inability to support stable soil development and therefore support vegetational growth. Many slopes are base sediment or rock, subject to physical weathering processes such as rock shattering and debris fall, as well as being prone to poor soil development and periodic soil erosion. High temperatures plus the position on the slope, and often extreme falls in temperature overnight, lead to quicker shattering of rocky substrates and may also induce greater erosion, often of rock rubble debris (Statham 1979; 1990). The combination of steep slopes and high amounts of physical and chemical weathering, give rise to fast but poor or no soil development really taking place. Mass movement slumping and slides and the truncation and denudation of slopes are common. In turn, these processes may lead to considerable quantities of eroded and transported soil and sediment accumulating in valley bottoms, both in mountainous and hilly areas as well as in wide river floodplains. Every part of the landscape is prone to the effects of storm events, often leading to incision and removal of soils and sediments and their re-deposition downslope, dependent on water volume, intensity and speed (Kirkby 1969a; 1969b). These repeated cycles of aggradation-incision-erosion-aggradation may occur in all kinds of periodicity, whether for example as occasional punctuated events, or more slowly and continually over time. All the while, human activities may aggravate these natural factors of instability in the system.

Concepts of threshold and balance are important in dryland landscapes (Gerrard 1992, 10ff.). Landscapes that are successfully exploited in such marginal conditions

usually require some buffering to make them sustainable, in the past and present. This may entail water storage and irrigation systems to temper the poor rainfall, as well as either diversification in their economy, higher mobility, or food storage and exchange systems. People, to survive in dryland systems, need to gradually insulate themselves from all but the catastrophic events. The recurrence interval of such events is also crucial to survival, or whether a change in life-style and behaviour is required to adapt to the perceived risk of repetition of the environmentally or climatically driven detrimental event. Thus, social, behavioural and economic conditions may be just as important, or more so, than changes in environment (Redman and van der Leeuw 2002). Thus the twin trajectories of climate-ecology and human endeavor are very interlinked.

Geoarchaeological survey in these arid to semi-arid landscapes is often easier than in more temperate, wetter and more stable environments. Incision and erosion generally present many opportunities for observing, recording and sampling deep sequences of landscape development which would otherwise be invisible. As in all other landscapes, creating your baseline data involves geomorphological and geological survey of your chosen valley system, identifying and mapping zones of slope debris, incision, slope-wash aggradation, alluvial accumulation, former palaeo-channels and associated river terraces (French *et al*. 1998; Ayala and French 2005). These data need to be superimposed on a terrain map using GIS methods if possible, backed up by the use of aerial photography if available and geological maps, and then related to the known archaeological record of the area. Usually, there is a coincident archaeological survey at the same time as your geoarchaeological survey, thus providing a perfect baseline for further interrogation and analysis. It is then a question of a transected approach to recover sequence in your valley-scape, and then to systematically sample and date the major stratigraphic units observed and recorded. This will develop the palaeo-catena through the landscape. Generally, you should be thinking of the use of radiocarbon and OSL dating techniques, requiring the presence and costs of employing other specialists from well known laboratories, as well as taking long sequences for palynological, phytolith and soil analyses from either valley fill and/or palaeo-channel sequences, with accompanying targeted soil sampling of any buried soils encountered.

The Rio Puerco example in New Mexico discussed below further exemplifies this approach (French *et al*. 2009b), as does the published geaorchaeological study of the Aksum area of northern Ethiopia (French *et al.* 2009b; Sulas *et al.* 2009). Further development of the latter project serves to illustrate project method and design that may be applicable in many dry land landscapes. It aims to investigate the trajectories of success and failure in sustaining viable agricultural systems in two semi-arid landscapes: Aksum in the north and Konso in the southern highlands of Ethiopia (AAREA Project, 2014–19). Konso is an example of agricultural sustainability despite longer-term and recent aridification (Abate 1992; Amborn 1989; Watson 2009), whereas Aksum is a landscape subject to past and present cultural and environmental stresses (Butzer 1981; French *et al*. 2009a). What are the causes of success and failure in these landscapes? What factors constrain the resilience of these landscapes? Can we learn what to do/not to do in terms of managing such landscapes in the face of environmental change, agricultural intensification and population growth? Can these lessons be applied to other desertifying landscapes in Africa and southern Europe? The

outcomes should provide fundamental contributions to the debate using a wide range of palaeo-environmental, geoarchaeological and historic-ecological techniques in an inter-disciplinary investigation of the Aksum and Konso landscapes over the last 5000 years.

The cultural ecosystems at Aksum and Konso are being interrogated through an integrative strategy using methods from archaeology, environmental sciences, and ecological, historical and cultural studies. Similar approaches are being used in both study areas: geoarchaeological and archaeological surveys, remote sensing, GIS mapping, test excavations, and interviews with local inhabitants which will chart the development through time of agricultural and irrigation features and settlements, and relate these to changes in demography, ecology and climate. The long-term impacts of land use are being addressed through an ecosystem approach that combines historical ecology and geoarchaeology. Soil and plant parameters provide indices of land use and vegetation history, while geo-chemical, physical, palynological and isotopic evidence offer proxy records of past climatic factors, set against well-dated cultural parameters. The combination of the two datasets should reveal whether these landscapes are either resistant (the ability of a system to return to a state of equilibrium after a disturbance) or resilient (a measure of the system's ability to absorb and adapt to changes) (Balée 1998; Slegers and Stroonsnijder 2008; Stump 2010). This whole ecosystem approach will lead to an understanding of the linkages between human-induced land degradation and sustainable agricultural systems for assured food production, and hence produce results that will have broad contemporary relevance as well as improving historical understanding of those localities (Crumley 1994).

Investigating temperate landscapes

In more temperate and damper landscapes, problems of preservation generally become exacerbated until fully waterlogged conditions are encountered. This often means the best and worst of dry and wet preservation factors are present, and most of the situations and factors outlined in the previous two sections also apply to temperate and damp contexts. Unfortunately, this is the most common type of context that most archaeologists and geoarchaeologists tend to work in, thus making assessing what should be done and what is actually achievable all the more difficult.

As would be expected, air is the major detrimental culprit to good preservation of organic remains. The fluctuating ingress and/or exclusion of air can be very damaging to the good survival of organic remains, not just macro-botanical evidence but also bone and poorly made artefacts such as many types of handmade pottery. Consequently, the nature of burial and the base status of the soil or sediment becomes very important in tipping the balance in favour of reasonable preservation or not. Calcareous or basic soil conditions usually mean that bone, molluscs, charcoal and carbonised macro-botanical remains will survive. Acidic conditions usually insure that these classes of data do not survive well, although charcoal should, and there may be the chance of pollen preservation as well for example. The depth of burial and/or the amount and nature of the overburden can also aid preservation. For example, a metre of fine grained calcareous silty clay alluvium, now dry and farmed, over a non-waterlogged, calcareous

buried soil may provide the air exclusion essential for good organic preservation, even including the pollen record (e.g. see the Welland valley section below).

With these caveats briefly outlined, it means that a very good initial assessment of all types of artifacts and palaeo-environmental remains is a must at the outset of any landscape or site specific investigation. One of the best ways to achieve this is through an auger transect approach as discussed in the previous section, backed up by aerial survey and mapping, and sample test pits, as well as sampling for the assessment of all classes of data to ascertain relative dating and preservation condition and conditions.

Data from modern soils and well preserved palaeosols and old land surfaces will usually be very informative with regard to providing long-term soil development trajectories which will greatly inform any discussion of landscape and land-use change. Well vegetated, calcareous soils such as brown earths and their varieties which are commonly found over much of Europe and Britain (Bridges 1970, 60–4) tend to preserve the pedogenic features indicative of sequences of landscape development, especially within their lower B horizons. These features are identifiable through the analysis of buried soils in thin section (or soil micromorphology) (Courty *et al*. 1989; Fedoroff 1968; French 2003; Goldberg and Macphail 2006). For example in generic soil development terms, it is often possible to observe the different microscopic features that denote landscape change from stable and forested conditions indicated by abundant, pure and well organised clays in the lower B horizon (or argillic Bt horizon) with a leached eluvial (or Eb) horizon above, to a de-forested and disturbed soil as indicated by dusty to dirty clay coatings in the lower B horizon and perhaps some secondary iron staining of the fabric, to a soil which becomes ploughed as indicated by mixed A and B horizon fabrics and dusty clay coatings of the voids in the lower A horizon. These types of soil development sequence are further explained as examples in the sections on the Welland valley and Cranborne Chase below.

3. Examples of fieldwork strategies and sampling applications for investigating landscapes

The lower Welland valley and Cambridgeshire fen-edge, eastern England

In the lower Welland valley between Stamford on the edge of the Lincolnshire limestone and the northern Cambridgeshire fen-edge at Borough Fen over a distance of some 20 km, what were some of the fieldwork strategies that were used to investigate the valley system? This landscape archaeology study has been published in four volumes (French and Pryor 2005; Pryor 1998; Pryor and French 1985; Simpson *et al.* 1993) and used a combination of existing data and targeted new field survey, excavations and analysis. Even though the project was not conceived as a unitary whole from the outset, it grew organically and is really the product of at least five different projects. In the end it has served to investigate the whole lower part of the valley system to the fen-edge, and has put forward ideas on prehistoric land-use change over time with respect to deforestation, agricultural intensification and gradual waterlogging of some parts of the system followed by more recent dewatering and desiccation.

The methodological approaches used fell into four major categories. First, a series of non-intrusive surveys and desk-top studies was made using existing sources of information. This involved compiling all the known archaeological, aerial photographic, drift geological and soil data and putting them together as overlays on the Ordnance Survey map of the area at one scale (1:10,000) (Pryor and French 1985, figs 3–5). Effectively, this defined various characteristics of the study region, and in particular showed immediately where the apparent blanks were in the archaeological record (*ibid*., Fig. 3). Today, these layers of data would have been constructed in a GIS, rather than by hand-drawn mapping to scale. Second, this was followed by a series of evaluation and assessment investigations. This mainly involved transect fieldwalking survey using 100 m sample swathes every kilometre from one watershed to the other across the valley floor (see Fig. 12), and dyke surveys of any cleaned drainage ditch sections with the stratigraphy recorded, described and levelled at least every 150 m (French and Pryor 1993). Then, third, there was selective intervention on the ground for a variety of reasons and involving several different scales of fieldwork and subsequent analysis. These included small test excavations of natural features such as palaeo-channels for sedimentological, ecological and land-use evidence (French *et al*. 1992; French and Pryor 2005, 3–7; Brown 1997) and, finally, selected, large scale excavation of waterlogged and/

or buried sites and non-waterlogged and plough damaged sites at Maxey (Pryor and French 1985), Etton (Pryor 1998) and Etton Landscape (French and Pryor 2005).

Some sites were excavated on an extensive scale in advance of destruction, mainly by gravel extraction and road building, and some sites were purely research excavation projects involving either full or sample excavation. At the pre-excavation stage, as many non-instrusive techniques as possible were utilised such as hand augering, geophysical, magnetic susceptibility and phosphate surveys. With the buried sites, such as the Etton Neolithic causewayed enclosure (Pryor 1998), the first stage of excavation was to remove the alluvial silty clay overburden and address the intact buried soil. Because of the excellent preservation of this old ground surface, non-intrusive survey techniques were re-employed at this stage. This included intensive gridded fieldwalking for artefacts, magnetic susceptibility survey and phosphate analyses (Pryor and French 1985, 34–58; Pryor 1998, 71–80). This kind of approach is of critical importance because on a plough-damaged site it is very unlikely to recover the more enigmatic types of evidence which may suggest human activities on the contemporary land surface. The second stage of excavation involved the removal of the buried soil to reveal the earth-fast features at the base of the soil and cut into the top of the subsoil, as one would find on any normal plough damaged site. As such large areas were investigated on many of the excavations and many of the features covered many hectares of land, this meant that it was impossible to dig all of the linear and non-structural features, so a 10% or 20% sample strategy was regularly employed for excavating these (Pryor and French 1985, fig. 40). On the other hand, structural, buried and waterlogged features were excavated in their entirety where time and funding allowed, with at the very least a 50% excavation of each feature. This leads into the fourth category of approach, establishing sampling strategies at the feature, context and horizon level, as well as the greater site-wide level (Flannery 1976 and papers therein; Plog 1976).

During the excavation of extensive, linear and non-structural features, one approach was to sample every layer in every section of each feature fills for wet and/or dry sieving for artefactual and palaeobotanical remains. Another approach was to be more selective and only sub-sample the primary fills, or to take only representative sets of samples from all major fill or context levels. Ultimately, the approach to be taken is very much a matter of the questions being asked of the site, the level of data and detail sought, and the time and funding available. This choice is never easy, and often with hind-sight one wishes that it had been done in another way at the time.

Sites or possible sites that were found by various survey techniques also required some further investigation by some form of evaluation. This could involve more detailed and site specific surveys, and/or sample excavation. Random, systematic or judgemental sampling excavation strategies could be employed, or some combination of all three methods. It is perhaps best to illustrate this by way of an hypothetical example. If there was a small lithic scatter on a small gravel island emerging from the peat fen which had been discovered by fieldwalking survey, where there was no other physical threat to the site other than drainage and arable farming, one could justify cutting say three 2 × 2 m squares. These should be spatially set with one test trench in the densest part of the flint scatter, one on the edge of the island and the margin of the flint scatter and one off-site to investigate the deeper, associated stratigraphic sequence. In all

three judgmental sample trenches, the aim would be to sample every possible feature, context and horizon for as many different analytical techniques as possible in order to maximise the information return. For instance, this could mean dry or wet sieving all of the buried soil in arbitrary spits for artefactual, faunal and charred plant macro-fossil remains, taking adjacent sample columns for molluscs, soil micromorphology and geo-chemical and pollen analyses, and bulk samples for uncharred plant macro-fossil and insect remains. This type of sampling and the information return from this sort of work can be seen at sites such as Crowtree Farm in the northern Cambridgeshire fens of East Anglia (French and Pryor 1993, 33–51).

From this type of investigation, where have the best environmental and archaeological deposits tended to come from? Almost without fail, the best preservation occurs at the margins, where the landscape gradually changes from one preservation situation type to another, such as at the base of slope, on the floodplain margin or adjacent to palaeo-channels. This type of context may be controlled by a variety of factors such as elevation, degree of burial, proximity to the groundwater table and the underlying geology. For example, in the floodplain and fen-edge zones of eastern England, the best position for good preservation regularly involves the subsoil dipping gradually down-slope over a long distance with a well preserved buried soil sealed by overburden deposits which are generally air-excluding, with a groundwater table at the level of the top of the subsoil but which remains more or less steady at this level year-round. In addition, deep features such as buried soils under monuments and palaeo-channels provide excellent contexts for *in situ* archaeological and palaeo-environmental preservation. Each of these types of context is potentially prone to various taphonomic agencies that may skew the sanctity of the context or feature or type of evidence, especially truncating flood events. But, as long as one is aware of these and openly test the data for the signs and mechanisms responsible for various distortions, there is no reason why these types of context cannot be relied upon to offer good archaeological and palaeo-environmental data.

The chalk downlands of Cranborne Chase and Wessex, southern England

On the chalk downlands of Cranborne Chase, the environs of Stonehenge and Durrington Walls (Richards 1990; Cleal *et al*. 1995; 2004; Parker Pearson *et al*. 2004; forthcoming) and the Maiden Castle area (Sharples 1991) in southern England, fieldwork strategies were employed that are broadly similar to those discussed above. But the techniques were often deployed over a much wider geographical range, and these were often associated with a particular monument or had a specific time period focus. Unfortunately, however, the survival of buried landscapes under either air-excluding or waterlogged deposits is generally uncommon in these well-drained landscapes. Here also there is often no overall conception by one project team over a lengthy period of study from site to site, landscape to landscape. As a complicating factor, many of the sites are scheduled, which makes archaeological field research much more burdensome to instigate and often curtails what may be attempted in terms of the scale of operations. Similarly, there have not been so many extensive and large-scale destructive developments such as gravel

quarries which allow extensive rescue excavation projects in advance of destruction, with a few notable exceptions such as Durrington Walls (Wainwright and Longworth 1971) and the A35 Bypass (Hearne and Birbeck 1999). For example, the strategy for investigating a series of scheduled prehistoric monuments in their landscape context in the upper Allen valley of Cranborne Chase involves aerial and terrain mapping, off-site auger transects (Fig. 25), prospection for colluvial/alluvial and river valley peat deposits (Fig. 26), sampling of palaeo-channel systems for their vegetational record, extensive geophysical survey and augering of individual sites with targeted sample excavation for structural and palaeo-environmental evidence (Allen 1992; 1997a; 1997b; 1998; French *et al*. 2000; 2003; 2007; French and Lewis 2005). In many instances, large research projects have been set up to deal with one monument, for example Maiden Castle (Sharples 1991) and Stonehenge (Cleal *et al*. 1995), or a whole associated landscape such as the Stonehenge environs (Parker Pearson 2012; Parker Pearson *et al*. 2004; forthcoming; Richards 1990) and Cranborne Chase (Barrett *et al*. 1991a; 1991b; French *et al*. 2007). The latter project in particular attempted to combine survey and selected excavation, extensive off-site and detailed on-site studies in combination with pre-existing and new environmental data.

The methodology of how this project was devised and executed is explained in some detail in French *et al*. (2007, 17–21), but the basic approaches can be summarised here. There were two main objectives. First, a selection of scheduled and unscheduled prehistoric monuments was re-examined, namely a selection of Neolithic long barrows, Bronze Age round barrows of the Wyke Down group, the Neolithic Dorset Cursus and the Iron Age Gussage Down field systems (Figs 11 and 27). These sites are situated in different landscape zones: high down, upper and lower down slopes and floodplain edge. Targeted sample excavation allowed environmental sampling for new pollen, molluscan and soil micromorphological analyses, especially from buried soils. This made possible the establishment of chronologically controlled palaeo-environmental sequences to augment existing studies in the area (Allen 1995; 1997; Allen and Green 1998; Green and Allen 1997). Second, the geomorphological survey of the upper part of the Allen valley utilised aerial photographic mapping of erosion versus aggradation zones in the landscape with respect to the known archaeological record, and systematic augering transects (normally *c*. 500 m apart with boreholes at 100 m intervals; and at *c*. 50 m transect widths at 10 m and 20 m intervals in the waterlogged floodplain areas) followed up by sampling trenches (where appropriate) to extract pollen, soil and molluscan samples from zones of colluvial and alluvial aggradation, old land surfaces and waterlogged deposits in relict channel systems in the valley bottom (Figs 25 and 26). This enabled the assessment of the processes of change and degradation in the landscape, and prospection for off-site buried landscapes containing new palaeo-environmental data. All these results were then combined to produce new models of land-use change in the earlier to mid-Holocene, new sub-regional palaeo-environmental sequences, and a re-examination of existing models, hitherto based largely on prehistoric funerary monument distributions and applications of social theory (cf. Bradley 1978; 1998; Barrett 1994).

On- and off-site palaeo-environmental and archaeological investigations of the upper Allen valley of Dorset revealed a model of landscape development which contrasts with those previously put forward for the region (French *et al*. 2007, 225–6). New

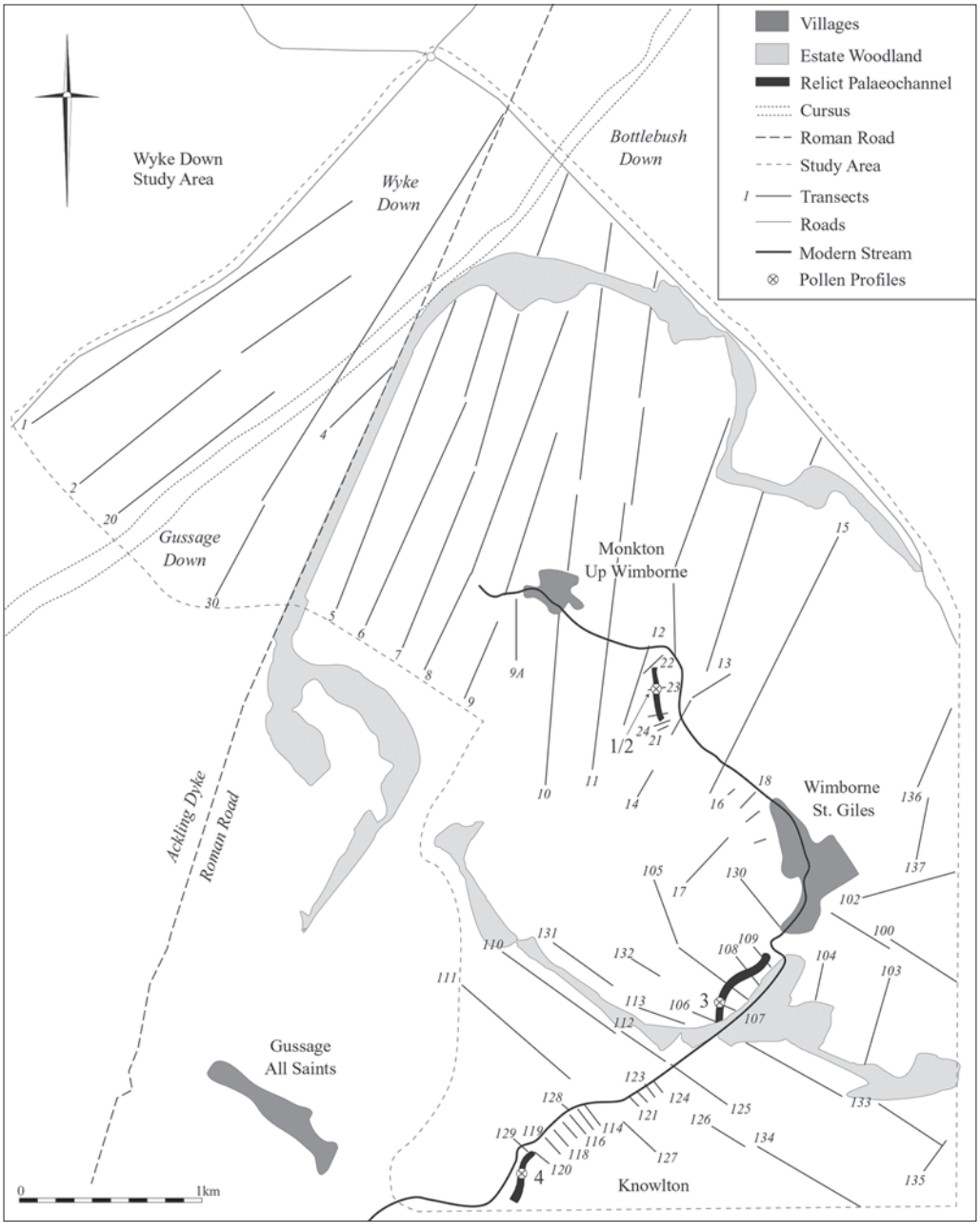


Fig. 25. The upper Allen valley borehole transects, Cranborne Chase (D. Redhouse after H. Lewis)

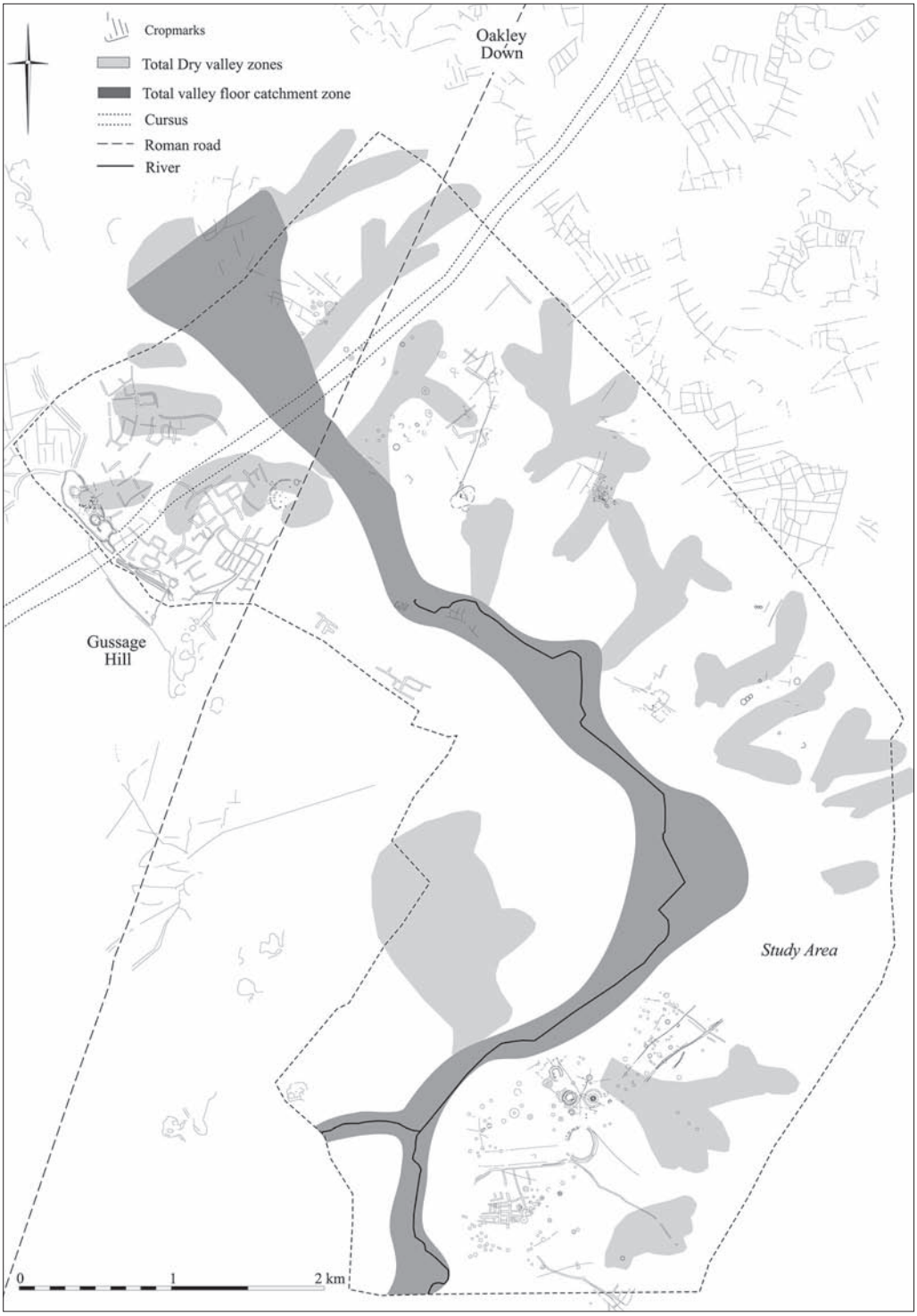


Fig. 26. Conventional two-dimensional plot of hillwash and valley alluvial deposits with the known archaeological record of the upper Allen valley, Cranborne Chase (R. Palmer)

data, especially palynological, molluscan and soil micromorphological, suggest that woodland development in the earlier Holocene of this landscape was more patchy and variable over space and time than the presumed model of full climax deciduous woodland. Finally, an attempt was made to interrogate and visualise some of this new data using dynamic ecological modeling in a GIS system, which has provided new ideas on the longevity of landscape management practices associated with livestock husbandry (see Figs 11 and 20; Samarasundera 2007, 197–206).

On the downland and in the valley bottom occupied by the Dorset Cursus in the upper part of the Allen valley, there appear to have been substantial open areas already

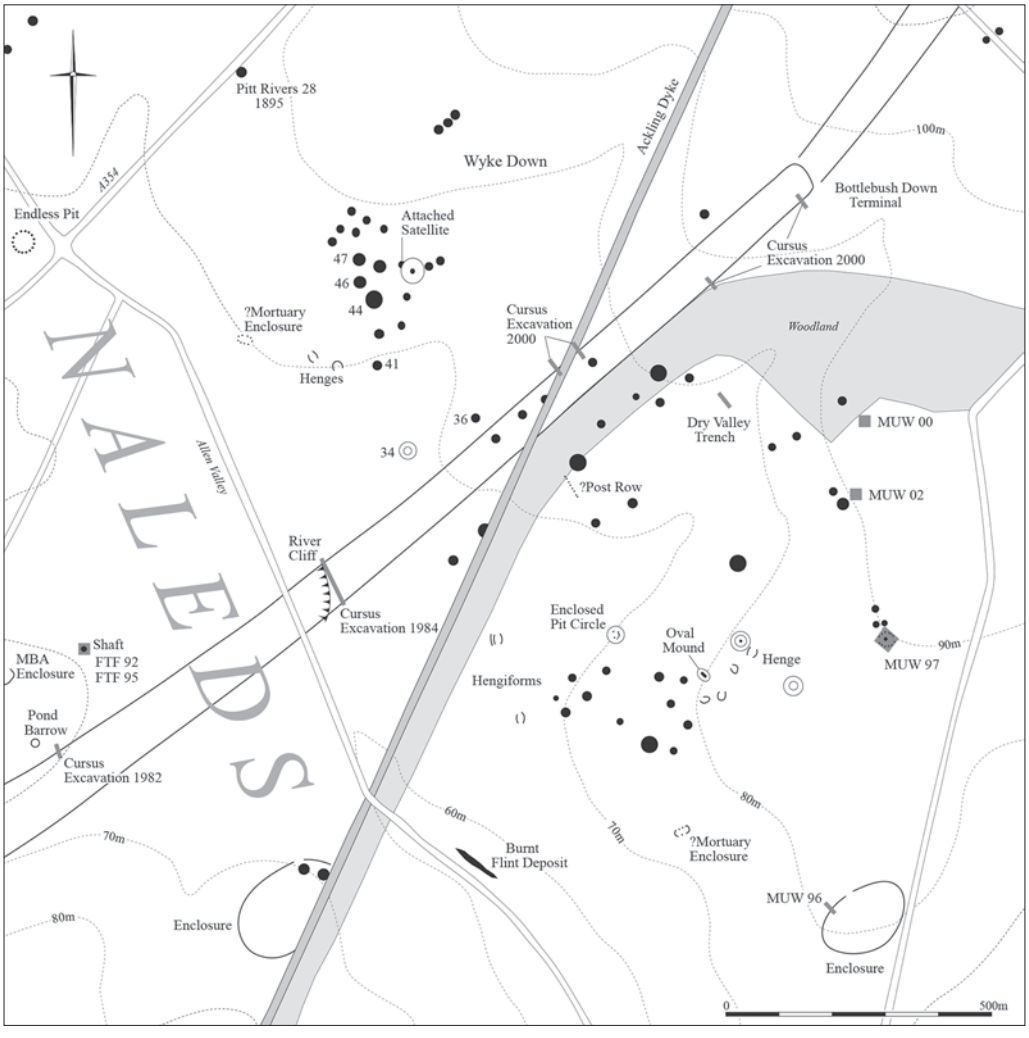


Fig. 27. The prehistoric archaeological sites of the upper Allen valley of Cranborne Chase (C. Begg after M. Green)

present in the Mesolithic. In this valley head area, soil change had already occurred by the 4th millennium BC. This involved a widespread change from more organic and clay enriched brown earths to thin rendzinas associated with established grassland, thus slowing and altering the soil development trajectory of this part of the downlands. Consequently, many areas perhaps never developed thick, well structured, clay-enriched soils (or argillic brown earths) as is suggested for the downs under forest, but rather thin, under-developed brown earths (Allen and Gardiner 2009; French *et al*. 2007). This landscape development route led to the concomitant establishment of a predominantly and long-lived grassland landscape by the later Neolithic period (French *et al*. 2007).

In contrast, further downstream in the southern part of the study area between Knowlton to Wimborne Minster, a different trajectory of landscape development was evident (Scaife in French *et al*. 2007). Here, mixed deciduous woodland did develop throughout the Mesolithic and earlier Neolithic, and witnessed its first clearance inroads in the mid- to late 4th millennium BC associated with a coincident elm decline. This landscape gradually became much more open and dominated by grassland over the next three millennia. But, evidence of increasing arable land use does not seem to have occurred significantly until later prehistoric and earlier historic times and again in recent late 20th/21st century times. Indeed, geomorphological survey and ditch fill studies throughout the whole study area suggest that neither significant nor extensive colluviation took place in the valley until historic times, with aeolian evidence for bare or tilled earth appearing only occasionally in later prehistoric times.

The combination of the presence of thinner and less well-developed soils over some large areas of downland by the Neolithic and long-established grassland environments removes the necessity for envisaging extensive soil erosion and thick aggraded deposits in the valley bottom occurring during the Neolithic and Bronze Age, as has been proposed elsewhere for the Wessex chalk downlands (Allen 1992; Bell 1992; French *et al*. 2007). The investigations suggest that if there were major changes in vegetation and soil complexes related to changing land use practices in the Wyke Down area, these had already occurred by the Neolithic rather than in the Bronze Age as suggested by previous researchers (Barrett 1994), and the area has remained relatively stable since. It is suggested that the creation and maintenance of this grassland dominated upper Allen valley landscape was probably as much due to livestock management as anything else such as ceremonial and burial activities. Yet, in other parts of the study area to the south, the more 'conventional route' of deciduous woodland development into the Neolithic and subsequent gradual clearance, predominantly for grassland, did take place. Thus, there is considerable sub-regional variation just within one 15 km reach of one valley system, both spatially and through time.

Nonetheless, the preservation situation in the chalk downland zone of southern Britain has not been conducive to looking for new sets of data in different parts of this landscape. First, existing theories on landscape change and development need to be tested with good sets of palaeo-environmental data. Obviously, this means finding new repositories of reliable and well preserved data. My hunch is that most of the river valleys draining this region such as the Avon, Allen, Kennet and Stour will contain hidden sequences of palaeo-channels and associated waterlogged, organic deposits

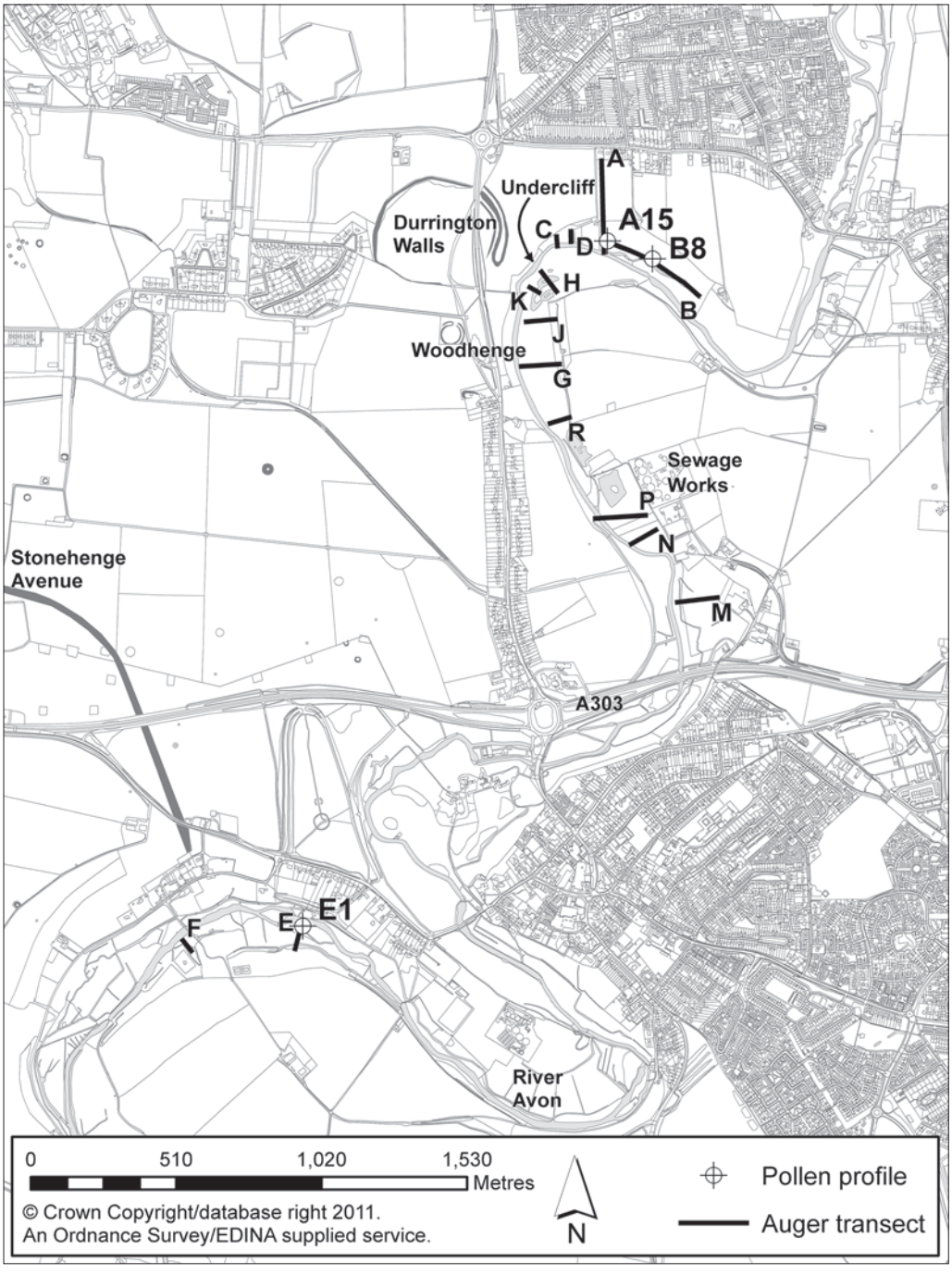


Fig. 28. The borehole transect locations between Durrington Walls and West Amesbury, (M. Dover)

which make detailed Holocene landscape reconstruction possible. This potential has now already been hinted at by geoarchaeological and palynological investigations in the upper Avon valley just to the east of Durrington Walls (Fig. 28) (Scaife 2004; French *et al*. 2012) and in the upper Allen valley of Cranborne Chase (French *et al.* 2007). In both the Allen and Avon valley cases, peat filled palaeo-channels have been discovered which still contain reliable Holocene pollen sequences for the immediate region. Despite the presence of calcareous groundwater conditions, this makes one wonder about the types of deposits that may be contained, as yet undiscovered, in say the Kennet valley in the vicinity of Silbury Hill and Avebury, the dry valley named Stonehenge Bottom which runs from the Stonehenge to the alluviated floodplain of the Avon just west of Amesbury, and the winterborne stream valleys to the north of Maiden Castle, to name just a few. Indeed, the recent discovery and sample excavation of the Mesolithic site at Blick Mead near Amesbury in the same Avon valley system with associated peaty spring deposits (www.buckingham.ac.uk/research/hri/fellows/jacques) appears to prove the point. These landscape zones require systematic investigation for the discovery of capture zones of palaeo-environmental data. Only then by looking for and testing new parts of the landscape will it be possible to examine how this most important area of Britain became so extensively exploited in prehistoric times, and decipher the specific trajectories of deforestation and agricultural intensification.

The central Rio Puerco valley, New Mexico

This project combined geoarchaeological survey with associated pollen, charcoal, micromorphological and radiocarbon analyses of a 5 km reach of the Rio Puerco channel and its tributaries centred on the Guadalupe Ruin, northern New Mexico (Fig. 29) (French *et al*. 2009b). This pueblo dates to the late 10th–12th centuries AD and is associated with Chaco Canyon (Baker and Durand 2003). This project aimed to build on the earlier geomorphological studies of the lower Puerco basin by Love *et al*. (1982), Nials (2003), Nials and Durand (2003) and Shepherd (1978). Unlike these previous examples, this project was particularly focused on a particular palaeo-environmental problem but with no accompanying archaeological interventions. Also the project was more of an assessment with follow-up analyses rather than an in-depth interrogation of the archaeological landscape. Initially, the project set out to investigate the palaeo-environmental circumstances of the effects of fire on Holocene riparian landscapes in the Rio Puerco basin. But during the course of fieldwork, the project became more of a stratigraphic study of the Holocene alluvial and floodplain soil sequence in this part of the Puerco basin and its tributary valleys. What were the sequences of stability/instability, incision and infilling in this reach of the Rio Puerco? What relationships did these events have to broader regional environmental signatures and occupation histories? And what were the implications of the observed burning events in terms of the nature of the burns and their scale and impact on the landscape? Finally the project also offered both contrasts and corroboration with broader regional and sub-regional trends and sequences.

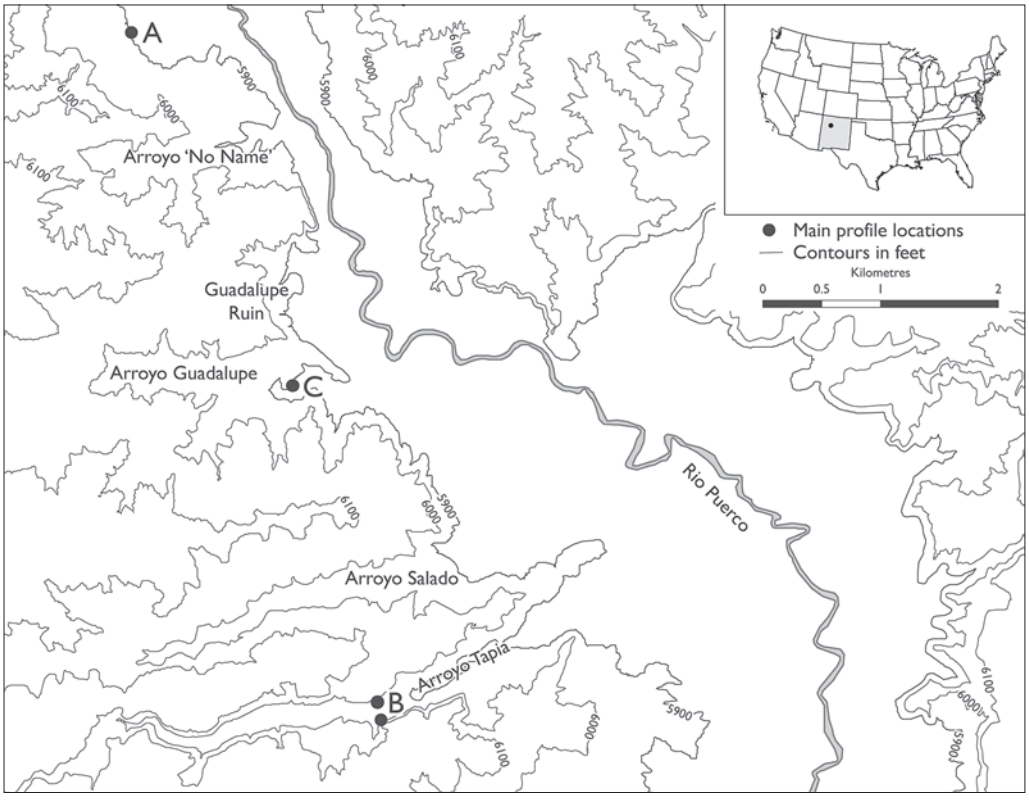


Fig. 29. The Rio Puerco, New Mexico, survey area and profile locations (D. Redhouse)

The geoarchaeological survey consisted of a valley-wide reconnaissance of all the extant arroyo profiles of the chosen area of the Rio Puerco and its four main associated tributaries. But given the scale of the landscape and depth of its arroyo profiles, basic geomorphological survey methods were then employed to record representative sections in both the Rio Puerco (Figs 29, 30 and 31) and the lower reaches of the four tributaries at a number of locations. These were chosen judgementally with respect to ease of access, completeness/depth of profile, and occurrences of possible buried soils and charcoal-rich and fire-reddened horizons. Of these 20 or so profiles, only two key representative sections, at A in the Rio Puerco (Fig. 30) and a similar profile B in the Arroyo Tapia, were recorded and sampled intensively (French *et al*. 2009b). From these two specific profiles, possible palaeosols and a selection of fire reddened lenses were judgmentally sampled for soil thin section analysis (after Murphy 1986; Courty *et al*. 1989) and description (after Bullock *et al.* 1985; Stoops 2003). In addition, a series of spot samples were also taken for palynological and charcoal analyses by Linda Scott Cummings (after Moore and Webb 1978; Moore *et al.* 1991) from these same Rio Puerco and Arroyo Tapia sequences. The charcoal lenses which were related to the major

Fig. 30. Profile A in the Rio Puerco, with the middle unit of cumulic buried soils of Unit D dated to about 2500–2200 cal BC located just above the author's head on the ladder (R. Periman)

stratigraphic units were targeted for AMS radiocarbon assay of charcoal. Over 50 AMS radiocarbon dates were determined in calibrated years BC at 95% probability using the calibration curves of Stuiver *et al.* (1998).

The geoarchaeological and palaeo-environmental assessment revealed that the depositional history of the Rio Puerrco basin study area around Quadalupe Ruin exhibited a consistent sequence throughout the last *c*. 6000 years (French *et al*. 2009b). The valley-fill sequence revealed a deeply incised, 11 m tall, alluvial sequence, interrupted by at least four phases of cumulic soil development (Fig. 31). Four major periods of instability occurred between these that were marked by thick accumulations of fine alluvial material: pre-5700 BC, for a lengthy period between *c*. 5700 and 2600 BC and 2200 BC and AD 350, and since the late 18–19th centuries AD. Associated with this are at least five major periods of palaeo-channel entrenchment at about 4000 BC, 2600 BC and AD 350, between AD 900 and 1300 and post-*c*. AD 1800, of which the later two may have broader sub-regional significance. This valley aggradational sequence was interrupted by four major periods of relative stability characterised by well-defined zones of cumulic soil development: for a period prior to *c*. 5700 BC, between about 2600–2200 BC and AD 350–550, and in the Puebloan period (*c*. AD 900–1400). Each cumulic palaeosol unit represents multiple and superimposed episodes of weak soil formation alternating with periods of more minor alluvial sedimentation which is indicative of seasonal aggradation in a floodplain edge situation.

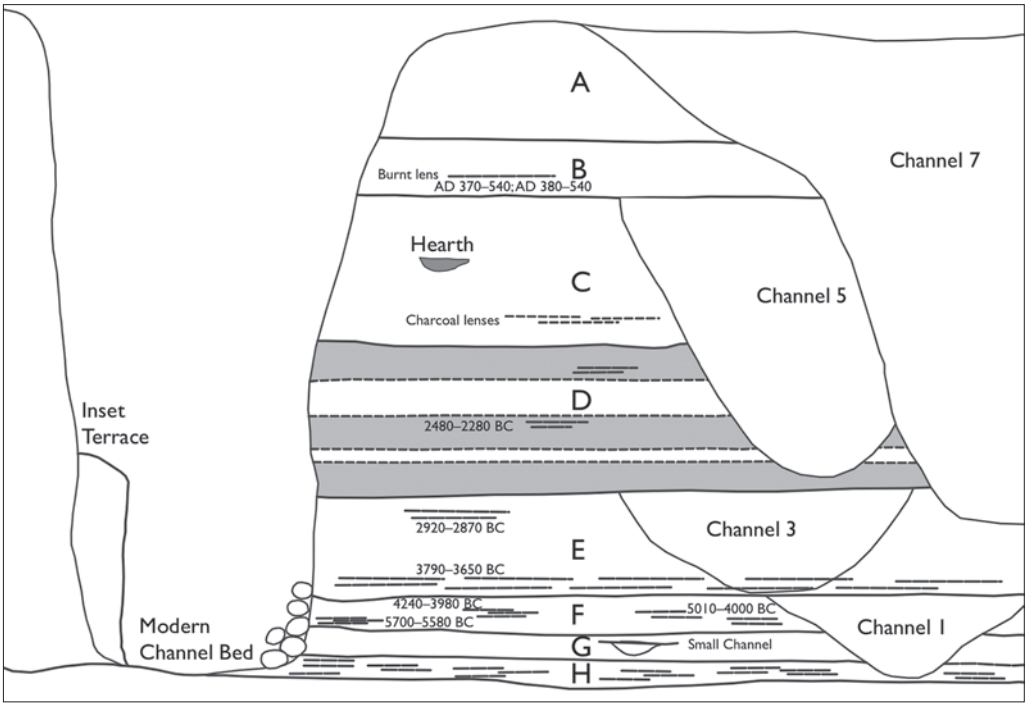


Fig. 31. Schematic sequence for the Rio Puerco (D. Redhouse after C. French)

The pollen data from the middle cumulic palaeosol horizon dated to about 2600–2200 BC and its two associated small channels is suggestive of sparse pinyon-juniper woods, with low frequencies of oak, set against a background of moist grassland (Scott Cummings 2004; French *et al*. 2009b). There was also willow and mesquite (at its extreme northern range) growing along the river's edge, with sedges, grasses and saltbush in the moist floodplain and along the floodplain margins. Multiple signatures of fires were particularly observed in the lower parts of the Arroyo Tapia tributary sequence, especially between about 6000 and 2600 BC, but continuing more intermittently until about AD 550 (French *et al*. 2009b). It is suggested that these fires may have helped enhance food resources for game animals by encouraging grass/shrub growth and/or to increase the growth of wild plants and latterly even cultigens like maize, which has a presence in the Arroyo Tapia by about 2600–2200 BC. The fire signatures in the pre-Puebloan Puerco sequence are much more likely to be related to more frequent, light surface fires in a more open environment than stand-replacing fires that may have led to large debris flow events.

The Rio Ica valley, Peru

Although this project: *Life and Water in the Ancient Southern Andes*, is currently in progress, it is a useful case study of how to approach a large valley landscape from a geoarchaeological perspective. This project aims to track the flux in cultural florescence and collapse through time along a single river – the Rio Ica – from its headwaters in the southern Andes to its mouth on a desert coast during the latter half of the Holocene (Fig. 32). Southern Peru's Pacific coast is one of the world's driest deserts, whose only sources of water are rivers arising in its rain- and spring-fed highland hinterlands. The Andes encompass tremendous variations in human ecology and support cultivation even to extreme altitudes and at tropical latitudes. Yet, despite the obvious interdependency between the hydrology and economy of coast and sierra, no investigation has yet taken the entire course of a single watershed as the unit of study within which to model changes and interactions in settlement, land use and water management. Overall, the project proposes to investigate the development of the Rio Ica valley from the Early Horizon (*c.* 750 BC) through to the end of the Inca Empire (AD 1534) by combining archaeological survey and excavation with GIS, hydrological, geomorphological, geoarchaeological and archaeobotanical methodologies.

Culture change in the ancient Andes is regularly explained by catastrophic climatic perturbations such as El Niño (El Niño-Southern Oscillation or ENSO) floods and droughts and wider regional climatic change, according to a model of punctuated equilibrium, with a much higher frequency over the last 3000 years (Carré *et al*. 2013; Eitel and Mächtle 2009; Sandweiss and Kelly 2012; Shimada *et al.* 1991). While recognising the importance of these types of events, one should also be developing previous research which distinguished the effects of more gradual, human-induced change (Beresford-Jones *et al.* 2009a; 2009b; Beresford-Jones 2011; French 2010a; 2010b; Lane 2009). To this end, the overall aim is to produce a long-term and detailed model of landscape, land-use and water management change through time along the course of the Rio Ica from its headwaters to its mouth, to answer three research questions:

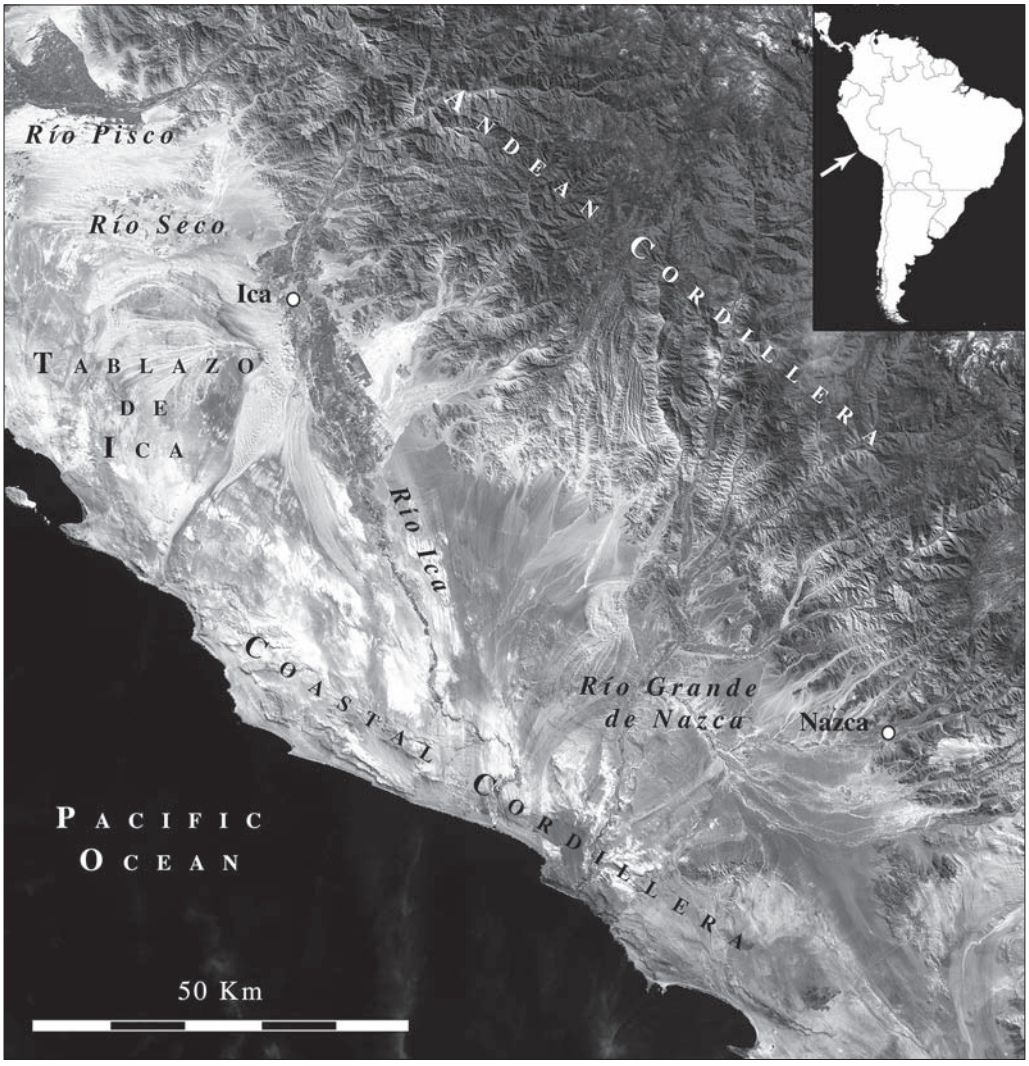


Fig. 32. Map of the Ica valley, southern Peru (D. Beresford-Jones)

1) How and when did settlement change along the drainage? 2) How does that relate to changes in water and land management? And 3) Why did these changes occur?

The first phase of the project has involved a geoarchaeological and archaeological reconnaissance survey of the whole reach of the Rio Ica valley, from the Pacific shore to the top of the watershed at about 4800 m in the Andean highlands, followed up by targeted fieldwork. This survey has located new and existing archaeological sites from which a number of sites have been selected for sample excavation, dating and palaeo-environmental analyses, as well as to investigate the history of the field and water irrigation systems integrally related to the settlement landscape.

Essentially on the basis of terrain, the valley falls into five main ecological zones: the Pacific coastal dune area (Fig. 33), the lower desert-like reach of the Ica from the modern city of Ica south-westwards interrupted by 'oases' such as the Samaca basin (Fig. 34), the eroded and highly modified desert margin dune system and lower highlands below *c*. 1800 m (Fig. 35), the highly developed field and irrigation systems with associated settlements in the highlands from *c*. 1800–3800 m (Fig. 36), and the more pastoral upland landscapes from *c*. 3800–4800 m at the top of the watershed in the Andes (Fig. 37). In each

Fig. 33. The coastal sand dunes and prehistoric middens at the mouth of the Rio Ica (C. French)

Fig. 34. The Samaca basin and a Late Intermediate settlement site H8 in the Ica floodplain (C. French)

Fig. 35. The highly eroded foothills on the desert margin of the Ica valley (C. French)

Fig. 36. The Andean highland terrace and irrigation systems of the mid-upper valley near Sangayiaco, Peru (D. Beresford-Jones)

Fig. 37. The high pampa pasture, peat bogs and springs in the upper Ica valley (C. French)

area, the protocol has been to identify and map the archaeological record on the ground, conduct terrain mapping of the identified sites and their immediate hinterland using GPS and GIS methodologies, and using existing rainfall and climatic data to model how the whole hydrological system functions today. On this basis, a number of sites have been selected for targeted sample excavation and hinterland geoarchaeological investigations. These include on- and off-site investigations of the coastal shell middens which are the vestiges of semi-sedentary societies exploiting a rich marine resource, which span most of the early Holocene from about 10,000 to 4500 cal BP (Engel 1957; 1981; Beresford-Jones, pers. comm.), floodplain agricultural and settlement systems in the lower valley reach, especially in the Samaca basin, that may have begun from as early as the early Ocucaje phases from *c.* 750 BC (Massey 1991; Cook 1999) and intensifying into the so-called Early Horizon (to 1 BC) and into the late Nasca period (by *c.* AD 800) and Late Intermediate period around AD 1000 (Beresford-Jones *et al.* 2009b), as well as sophisticated highland systems of hydraulic management supporting multiple settlements throughout the last two millennia, which appear to be underpinning a complex, mixed farming and agro-pastoralist economy (Lane 2006; 2009), and finally the spring-fed pastoral systems which are evident at the highest altitudes at the top of the Ica watershed in the Andes.

Once a platform of data has been established which chronicles how the system functioned in the past and operates today, it should be possible to turn to the more vexed questions of how and why change occurred. In previous research, historical ecological approaches (Balée 1998) have suggested that variable impacts upon the landscape were caused by various land-use and water management strategies that were adopted at different times by different societies in the past in the lower Ica Valley (Beresford-Jones 2011; Lane 2006; 2009). Now the aim is to expand the scale of that analysis to produce an integrated picture along the whole Rio Ica drainage for how watershed management and land-use have interacted with the flourishing and collapse of cultures through time against a back-drop of wider climatic changes over the Holocene. Whilst including consideration of the frequency and veracity of the impacts of major climatic perturbations such as El Niño events, it should be possible to acquire a more complete account than hitherto of the role of human agency in creating, managing, reacting to and sometimes provoking detrimental, landscape change.

Initial observations

The Rio Ica and its associated tributary rivers in their upland areas are essentially an active erosive system which have become periodically stabilised by large-scale human activity and field terracing and hydraulic engineering enterprises. Alarmingly, the peat bog areas of the high pampa above *c.* 4000 m no longer appear to be stable as there is new and active head-cut erosion taking place (Fig. 37). This is strongly suggestive of present day over-grazing of the steppe-like grassland by today's sheep and cattle grazing, a situation possibly aggravated by surface drying caused by either shifts in rainfall pattern or lowering of the natural groundwater table.

Ancient field and irrigation systems are better preserved between about 1800 m and 3800 m in the Rio Ica valley (Fig. 36). Old land surfaces, buried soils and colluvial soils

are frequently observed. Nonetheless, there is active gully incision on many slopes, and especially in the lower height range of the Ica valley (Fig. 35). Again, how much this is controlled by changes in rainfall intensity and patterns, versus much more limited farming use of these terraces over the past few decades leading to the collapse of the retaining wall systems through a lack of maintenance, is a matter that requires investigation. Yet, there is no doubt from initial observations that these past irrigated terrace systems are capable of providing suitable conditions for the development of good, thick, organic soils that are fertile, at least at face value. Was this always the case? How were these soils managed in the past to sustain agricultural use on such a large scale? These are important questions that need to be addressed in order to understand the development and settlement use of the middle reaches of the Ica valley.

The area occupied by the modern city of Ica is a highly human-altered desert environment bisected by the Pan-American highway. This transformation of much of this desert to an extensive fruit and vegetable growing landscape to either side of a sprawling city has occurred in the last few decades, and is almost entirely dependent on the abstraction of freshwater from the deep underlying aquifer. This zone has been almost impossible to survey and investigate from both archaeological and geoarchaeological perspectives.

The lower and coastal estuarine areas of the Ica system are also a highly erosive environment with both accumulation and incision on a massive scale. Nonetheless, there appears to have been considerable human adaptation to this degradational environment, and periodic, probably lengthy, phases of sustainability and use within them. The 2000–800 m lower mid-valley zone of the Ica is marked by severe surface degradation, colluvial and alluvial fans, river incision and very limited zones of valley slopes available for agricultural use (Fig. 35). The Ica city area is much ruined by urban sprawl and deep water abstraction of both the groundwater and the aquifer over 100 m below (Hepworth *et al*. 2010; Ore *et al*. 2014). Further downstream and to the south-west, geoarchaeological fieldwork in the Samaca-Ullujaya-Callango basins of the lower reach of the Rio Ica and has revealed a series of at least seven floodplain soils interrupted by episodes of river avulsion and/or windblown fine sand/silt deposition (Figs 38 and 39). These sequences date primarily to pre-late Nasca times and appear to span most of the mid-Holocene development and infilling of the lower Rio Ica over a depth of at least 6.2 m. There is a minimum of seven floodplain soils that are observed to have formed in alluvial aggradation deposits of fine sandy-silty clay loam. These soils are well structured and indicative of relatively lengthy periods of stability, probably measured in terms of 50–200 year periods. There is also evidence of wetting/drying cycles with manganese and calcium carbonate formation, silty clay and clay illuviation and structural development, as well episodic accretion of both windblown fine sands to silts and laminar riverborne sands. Nonetheless, these alluvial soils offered the possibility of floodplain agricultural use before the onset of aridification and variable erosive destruction of that floodplain landscape, especially because of their good structure and moisture retention characteristics. These soil development stages alternate with relatively brief changes of river flow and channel re-orientation, most probably associated with El Niño flooding events, as well as periods of wind-blown material deposition (Fig. 39), probably largely generated from dry riverbed exposures

Fig. 38. The Ica river's edge profile in Ullujaya, Peru, deeply incised by the 1997–8 El Niño, showing the alluvial sands and soils cumulative profile (C. French)

Fig. 39. Two major horizons of well structured alluvial silty clays alternating with wind/water-lain silt and very fine sand deposits in the Ullujaya basin (C. French)

on the valley floor, as well as from the sand dunes along the foothills of the Andes some 25 km further inland.

Major changes in the nature of the alluvial floodplain soil characteristics have also been observed. Notably there is a substantial increase in calcium carbonate in the floodplain soils over time such that the soil texture changed from being predominantly

well structured silty clays to massive calcitic fine sandy silts. This change appears to have begun to take place from late pre-Nasca times, or from about the last 1800–1500 years. At the same time there is also an increasing frequency and soil textural change to a greater dominance of silt and the very finest quartz sand which is indicative of a much greater aeolian input into the alluvial floodplain system. Similarly the inclusion of eroded tonalite bedrock fragments (from the Andes upstream) also begins to be seen in the alluvial floodplain soils. These three significant features strongly hint at changing climatic conditions, becoming drier and more punctuated by El Niño events, combined with greater disruption in the landscape that would have been associated with the agricultural terrace and irrigation systems in the Andean uplands of the Rio Ica valley. What is now required is a tighter chronology using OSL techniques for the lower Ica valley so that the possible palaeo-environmental changes observed in the soil record there can be placed against the evidence for climate history in the wider region of southern Peru.

There has been much recent incision and destruction of soil/sediment and archaeological records of the Ullujaya-Samaca basin area. In particular, the 1997–8 El Niño caused *c*. 5–7+ m of incision (Fig. 38) and the entire removal of one (of two) Late Intermediate settlement site situated in the Samaca floodplain. The question is when did this apparently relatively stable floodplain environment change so dramatically to becoming more affected by violent storms and incision events? There are some clues in the H8 Late Intermediate site (radiocarbon dated to *c*. AD 1000) step section excavated in 2013 (Fig. 40). Here, all the lower old land surface levels (5+) are interrupted by *c*. 20–60 cm thick horizons of fine-medium sand deposition. These appear to be reworked, transported and redeposited channel bed and/or dune deposits, and could indicate a greater aridity as well as stronger erosive effects in the valley system. In turn, these could be associated with more severe and frequent El Niño conditions as well as greater human interference with the soil and water system in the upper part of the valley over the past *c*. 3000 years or so (Carré *et al*. 2013; 2014; Etayo-Cadavid *et al*. 2013), and postulated

Fig. 40. The step trench profile through the H8 Late Intermediate tell site at Samaca, Peru, showing the thick fine sand accumulations between stabilised, brown occupation horizons (C. French)

periods of greater aeolian transport suggested at *c*. 1500–700 years ago (Eitel *et al*. 2005; Londono *et al*. 2012).

Finally the Rio Ica estuary where it empties into the Pacific preserves a number of Early Holocene, mainly Middle Pre-ceramic (*c*. 9000–5500 cal BP), extensive middens and dune accumulations which will provide some indications of an earlier Holocene environmental landscape system to compare to the Samaca-Ullujaya basin inland. The geoarchaeological work at the earlier and later Middle Pre-ceramic midden sites of La Yerba II and III (dated to 7571–7030 cal BP and 6485–5893 cal BP, respectively) has identified repeated sequences of possible floors, hearths, redeposition of hearth rake-out material, and periods of shifting occupation and/or abandonment. Importantly, it is suggested that rudimentary floor surfaces were made by using silt and silty clay alluvial deposits found in the Rio Ica floodplain margins. The 'cemented' aspect of many of these surfaces is a mainly a post-depositional phenomena caused by evapotranspiration and the secondary formation of amorphous calcium carbonate, sesquioxides and humified organic matter.

The prehistoric landscape of Herm island

A combination of auger, topographical and geophysical surveys, coastal prospection and targeted trial trench excavation enabled a series of exposures of old land surfaces and buried soils to be investigated as part of an archaeological project exploring the impact of Neolithic settlement and burial on the island of Herm (Fig. 41) (Scarre and French 2013). Palaeosols and old land surfaces associated with the Neolithic tombs and possible settlement sites were investigated using soil micromorphological techniques (after Courty *et al.* 1989) in order to decipher sequences of soil development, landscape change and land-use history of the northern part of Herm island throughout the Holocene. Trial trench investigations were conducted at four chambered tombs (Kendrick tombs 6, 12, 13 and 15) as well as further off-site trial trench investigations to investigate palaeosol profiles between the monuments and beneath variable depths of sand dune deposits in the northern half of the island known as the Common. Together these exposures enabled detailed appraisal of the earlier prehistoric and Roman period land surfaces and the immediately associated burial deposits that were revealed during the auger survey and trial excavations.

A consistent occurrence of an old land surface and palaeosol was found during the auger survey of the Common area on the northern third of Herm Island and also on the northern and eastern coasts of the northern part of the island, and in the area south of Robert's Cross (Fig. 41, tomb 12). This geoarchaeological survey and test excavations exposed buried soil profiles suitable for soil micromorphological block and small bulk sampling as well as a thorough programme of OSL dating (Scarre and French 2013; Bailiff *et al*. 2014). Forty samples from 20 soil profiles were prepared for thin section analysis (Murphy 1986) (see Appx 2 and 3) with associated analyses of a suite of basic physical parameters (pH, loss-on-ignition, electrical conductivity and magnetic susceptibility) and multi-element analysis (ICP-AES) (Avery and Bascomb 1974) (see Appx 1). From the borehole and trial trench data it was possible to create transects of

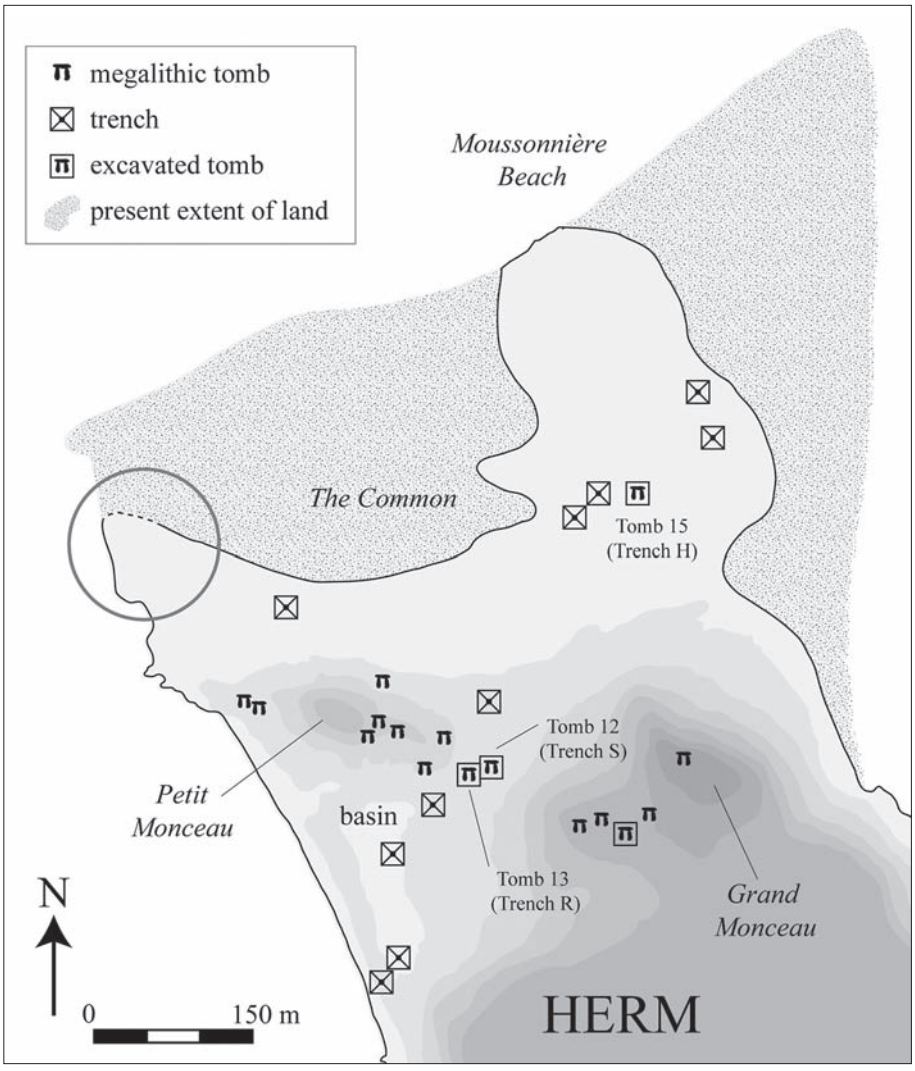


Fig. 41. Location of the chambered tombs and archaeological trenches on Herm in the Channel Islands with the stipple shaded area indicating how the island has expanded with the deep accumulation of sand dunes in historic times (K. Roberts, with permission of C. Scarre)

the height/depths of the old land surface across The Common and a contour plot of the previous shape of this northern part of the island (Fig. 41).

The pre-sand dune, old land surface is present quite consistently between the Bear's Beach on the west to Moussonniere Beach on the north (Fig. 42), at the footslopes of Le Petit Monceau and Le Grand Monceau to the south, especially associated with the Roberts Cross Neolithic tomb 12 (Fig. 43), and in the slope face above and to the south

of Belvoir Beach. The old ground surface generally defines about 2.75–3.4 m beneath the modern ground surface in the Common area. Nonetheless, it is apparent that the actual area of old ground surface present beneath the sand dunes is about one-third smaller in area extent in prehistoric times than the land area of today (Fig. 41). Indeed the pre-sand dune old land surface is not evident over much of the most northern and eastern parts of the Common, and it is believed that there was a large but shallow marine embayment present in the northern part of The Common which was becoming a peat-filled back-marsh by the Roman to early medieval period.

The buried soils where preserved are generally the lower half of a decalcified brown earth to weakly acidic argillic brown earth type with a clay-enriched B horizon (or argillic Bt) present at its base (after Avery 1980; Bridges 1978). This soil type was observed quite consistently but in varying degrees of development and preservation. The argillic Bt horizon is characterised by the presence of both non-laminated and occasionally micro-laminated, pure and dusty clay coatings and infills towards the base of the profile (Bullock and Murphy 1979). In addition, the buried soil has a predominant very fine sand to coarse silt component throughout which suggests a substantial wind-blown or loessic component. This wind input of coastal sediments to the soil cover of the northern part of Herm was certainly present by late glacial times, and has continued to be observed as a major component of soil/midden profiles from the late Neolithic to Roman times on Herm and on the adjacent island of Jethou (Morrison and Simpson 2008) and over much of the nearby island of Alderney (Hazeldon 2003).

Fig. 42. The Neolithic old land surface sealed beneath medieval sand dunes on Moussonniere Beach, Herm (C. French)

The degree of woodland cover associated with this soil is as yet uncertain due to poor pollen survival in this palaeosol, but there are hints of a developing late glacial-early Holocene pine-birch woodland present (Scaife in Scarre and French 2013). There is much better pollen data present from peat beds on the north coast of Guernsey which does indicate widespread deciduous woodland growth in the earlier Holocene (Campbell 2000). Certainly, the often well organised fine illuvial clay and silty clay components of the palaeosol strongly hint that this soil developed in association with a stable and well drained vegetational complex such as woodland (cf. Bullock and Murphy 1979; Fedoroff 1968; Macphail *et al*. 1987).

There is the strong possibility of *in situ* ploughmarks defining at the base of the former topsoil (or lower A/B horizon transition boundary). This is seen clearly in the palaeosol on Moussonniere Beach (Fig. 42) and around Tombs 12 and 13 (Fig. 43) with an agric horizon, compaction zones and illuvial dusty clay present (Macphail *et al*. 1987, 1990; Kuhn *et al*. 2010), which together with the sand-filled cut features are indicative of ard ploughing (Fig. 44)

Fig. 43. OSL sampling of the Neolithic buried soil/dune/Roman buried soil/dune sequence at Kendrick Tomb 12, Roberts Cross, Herm (C. French)

Fig. 44. Possible ard marks defining at the lower A/upper B horizon transition in the palaeosol to the north of Roberts Cross tomb, Herm (C. French)

(Gebhardt 1992; 1995; Lewis 1998; 2012). This occurs along with abraded small flint and pottery artefacts of Neolithic age in the B horizon. Indeed post-clearance ploughing in Neolithic times associated with the building of the chambered tombs could be partly responsible for creating the environmental conditions necessary to allow the subsequent extensive truncation of this early Holocene soil. This is a consistent feature of all the palaeosol profiles observed and analysed in The Common area. Once devegetated, this granular, very fine to fine quartz sand-dominated soil would have easily been subject to drying out and wind-blow, thus leading to rapid deflation and truncation effects. This is probably the reason why most of the buried soils observed in this research project were missing their upper organic A horizons. In addition, the associated surface horizon disturbance caused by a combination of ploughing and truncation with rainfall impact on an open and largely fine granular soil system would have led to both within-soil illuviation down-profile of fines (clay, silt and fine organic matter) (Macphail *et al*. 1987; 1990; Kuhn *et al*. 2010, 221), as well as their depletion leading to more sand-dominated soils. In short, any de-vegetating activities on this soil would have soon led to both soil destabilisation and the depletion of fines material and nutrient degradation, making the sustained use of this landscape for agriculture in the past very questionable without intensive manuring and planned management.

In the Kendrick Tomb 12, Robert's Cross profile, there is a basal argillic brown earth which is directly associated and beneath the kerb stones of the tomb as the pre-Neolithic soil (Fig. 43). But its upper surface appears to have been truncated, possibly by wind-blow and/or human activities, perhaps even associated with tomb building itself. A period of sand dune accumulation follows, then re-stabilisation with the accumulation and growth of organic matter and incipient soil formation, probably in the late prehistoric to Roman period, before dune formation renews, certainly by post-AD 1200 as indicated by the optically stimulated luminescence (OSL) dating study (Fig. 43) (Bailiff *et al*. 2014).

In some other trenches south of Roberts Cross, the palaeosol profile is in fact comprised of two superimposed soils and is essentially a cumulic soil (Holliday 2004, 91–4). The lower soil is a well structured sandy clay loam. This exhibits many dusty/dirty, silty clay coatings with much included fine humic 'dust,' both coating and linking sand grains and within the void space, but with some micro-laminated dusty clay coatings also occurring. These illuvial features strongly suggest that this is a slightly depleted argillic Bt horizon of an earlier soil. This soil has suffered considerable surface disturbance, much depletion and the addition of organic matter, such that it could have been ploughed in the past. Above this partly truncated *in situ* soil there is an horizon of slightly organic, fine-medium sand accumulation about 25–40 cm thick, most probably derived by wind-blow from the local foreshore and/or reworked shoreline dune system. Then there is an upper soil composed of a poorly sorted, fine-medium sand with the sand grains exhibiting a humified dark brown to black organic 'dust' adhering to and linking the sand grains. This bridged grain, wind-blown sand matrix has most probably resulted from plough agriculture, indeed as the narrow ard plough-like 'scratches' on its upper surface testify (Macphail *et al.* 1990; Kuhn *et al*. 2010; Lewis 2012). There are also several thin (2 cm), very dark brown humified horizons within this former ploughsoil, which could represent temporary standstill horizons and/or slight plough

pans at the base of a variable depth plough zone. Thus it appears that this former topsoil is continuing to aggrade through wind-blown additions at the same time as it is being ploughed. Nonetheless, the amount of humified organic matter present is atypical and suggests that some attempt may be being made to enhance the fertility and moisture retention capabilities of this soil as well as help stabilise this soil from localised erosion and wind-blow through the addition of organic matter. Indeed, the abundance of small, abraded pottery sherds within this ploughsoil may suggest that household-derived midden material was deliberately spread on this soil to create a better tilth. Thus in this respect, this upper soil represents a 'dark earth' type of soil (Macphail 2000; Goldberg and Macphail 2006). Optically stimulated luminescence (OSL) dating suggests that this organic soil was in use from late prehistoric times with two date determinations of 310±170 BC and 380±170 BC, but was still being used in Roman times as testified to by numerous included pottery sherds (Scarre and French 2013; Bailiff *et al*. 2014).

Wider implications

The range of palaeosols investigated from across the northern half of Herm are able to provide a composite soil and landscape history throughout the Holocene period. First, there is the development of a slightly acidic argillic brown earth by the 4th millennium BC, probably associated with a well-drained and developing woodland on the weathered granite geology of the island. This soil also has a strong loessic or wind-blown silt and fine to very fine sand component, probably derived from the previous dry and cold conditions of the late glacial period. As a result of the predominant fine textured (i.e. very fine sand, fine sand and silt) components of this type of soil, it would have had large reserves of water available for plant growth, at least initially. But, this soil type tends to be structurally weak, with a relatively low clay component and a very poor organic status, such that if used intensively there could easily be a combination of run-off, soil drying and/or soil erosion, particularly if ploughed and/or trampled. Subsequently this soil was opened up, and was much disturbed, probably by a combination of clearance and plough disturbance, wind-blow, surface run-off and hillwash effects. Exactly when this occurred is a matter of some speculation, but stratigraphic associations with the Robert's Cross tomb suggests that this had occurred by the time the Neolithic tombs had been constructed, or within the earlier part of the 4th millennium BC. In a few places, subsequent use during the Roman period is attested through the associated accumulation of midden material in old topsoils, and is corroborated by OSL date determinations (Bailiff *et al*. 2014). This activity would have served to add a much needed organic 'mulch' to the soil, more or less creating a 'dark earth' soil which would have been a valuable localised resource for arable agriculture. Similarly the humic organic 'dust' that characterises many profiles indicates that there was once a much greater organic component to this soil that has become highly humified and mixed with the soil 'skeleton' of fine sand grains. This may well represent deliberate additions of organic material such as seaweed, byre derived bedding material and/or settlement derived rubbish as a form of manure. This would have helped to counteract the natural acidity of the argillic brown earth soil on the bedrock granite of the island

and have added much needed organic 'body' to this particulate soil which in turn would have helped to counteract its naturally erosive tendencies.

Nonetheless for the most part, ploughing and associated run-off and hillwash processes, as well as the stop/start accumulation of wind-blown fine-medium quartz sand derived from exposed sandy foreshores, appear to have been widespread occurrences across the northern part of the island prior to the 20th century. In particular in later prehistoric and in post-Roman times, wind-blown aggradation of fine-medium sand deposits became widespread and of greater intensity. These features in turn imply that changes were occurring to the coastal morphology of the island, particularly around the northern shores of the island, with greater exposed areas of foreshore and possibly a greater intensity of storms. During the Roman period there appears to have been a return to somewhat more stable local climatic and shoreline conditions with an intense period of arable agriculture. Nonetheless, it seems that a conscious effort was made at managing and conserving the fine sandy soil with the addition of organic material of some kind, as well as with settlement midden-derived material, but with minor, episodic wind-blown sand accumulations still occurring. Subsequently there was a more major phase of wind-blown sand aggradation, with multiple standstill events marked by short-lived turf development. Optically stimulated luminescence dating suggests that this windblown sand and dune development phase had been certainly occurring from AD 1200 (Scarre and French 2013; Bailiff *et al*. 2014), and indeed dune accumulation and blow-outs are still occurring today.

4. Approaches to investigating settlement sites

Tackling archaeological sites with evidence of settlement structures and spaces utilises much of the same thinking about research design, the types of data necessary to be retrieved, the sampling techniques used and the interpolations needed to begin to make something out of the layers of data preserved. It is just that the space is more confined, delimited, and often multi-layered over great depths and discontinuously preserved spaces. First, it is preferable to have the structure well buried and sealed from later destruction, and second to know and understand the nature and position of the boundaries of the built structure that you are dealing with. It is also best if the structure has been as undisturbed as possible subsequent to its use in life. Obviously on an accumulating tell settlement site, there will potentially be lots of post-depositional

Fig. 45. Taking a series of overlapping 50 cm long monolith tins through a later prehistoric palaeochannel sequence at Must Farm, Cambridgeshire (R. Scaife)

burial and disturbance features as well as much potential for distortion of the burial record almost as soon as it is deposited/accumulated. This includes biological reworking, new flooring, changes of use and/or rebuilding, new foundations and pits being dug and superimposed buildings often re-aligned as well as the erosion and truncation of horizons and deposits. Similar things can occur in singular and multiple phases of floor and occupation levels. At open-air sites, superimposed phases of use may be compounded by changes in groundwater table, the deposition of sediments above, and/or more recent agriculture, all of which can disrupt the preservational sanctity of the structure and its living deposits. Ideally, the floor-occupation sequences require burial conditions that do not physically disrupt or truncate them, such as by the accumulation of wind-blown sand, deliberate backfilling or midden deposition, or another floor being built above. Throughout, the best case scenario is to obtain as many replicate samples as possible, taken at regular and consistent intervals, both spatially and by depth, across the interior of the structure. Moreover, samples should not just be taken for micromorphological and geo-chemical analyses, but the full range of other artefactual and palaeo-environmental data from faunal remains to molluscs and charred and uncharred plant remains and phytoliths for example (English Heritage 2002; 2004), as well as experimental and ethnographic observations and interpretative analogies (Banerjea *et al*. 2015; Boivin 2000; Briz *et al*. 2011; Shahack-Gross 2011).

Sampling strategies and techniques

It is advantageous to sample within any settlement or structures as systematically as possible, but also to obtain background samples from beyond/outside the structures for comparison. One of the most important aspects to establish first is how well buried and disturbed/undisturbed the structural components are, and then to assess the physical and geo-chemical parameters of the burial context. Is the structure and its associated internal deposits relatively free from post-depositional distortion and physical disruption, by secondary occupation and/or modern ploughing in particular? Is there a high local groundwater table and the possibility of waterlogging and/or air exclusion? Has the site been buried by a single event such as a massive flood event or the destruction of the structure and the building of another above, or a slow gradual aggradational dynamic such as building dis-use and/or seasonal alluviation?

If we take such a hypothetical example of a single horizon floor/occupation sequence of say a small Roman villa situated on river terrace gravels sealed beneath a thick alluvial ploughsoil with a high localised groundwater table and low footing walls surviving made of limestone blocks, what would be the most systematic way of sampling this structure? The idea is to sample from within and to the outside of the structure, horizon by horizon, so that all contexts present are investigated, including the available on- and off-site soil profiles. Recent experimental work (Speed 2014) has suggested that sampling from the upper 1 cm of each floor surface, and again at 5 cm below the surface, is crucial to gain the best geo-chemical fingerprints of former activities associated with that surface.

Soil/sediment sampling can use any of three different approaches, either singly or in any combination. This may consist of judgemental or continuous sampling of vertical

sections, paying especial attention to characterising the different horizons and the horizon boundaries (Figs 45, 46 and 57), or some kind of systematic 'checker-board' sampling approach (Figs 47, 48 and 50), or using a transect approach with temporary baulks (see Fig. 51). The first type of sampling approach is regularly usually used in test excavation trenches and essentially enables an evaluation of the archaeological deposit sequence to be undertaken, whereas the second and third field methodologies require some kind of larger open area excavation.

In the second approach, there would need to be some regularly spaced section baulks (which need only be temporary fixtures for ease of sampling) located at right-angles to and across the structure, and that extend preferably for up to 10 m beyond the walls of the structure. This method is best used where there is open area excavation of some kind. The baulks would be used to sample all horizons within the structure at regular intervals of 0.5/1/2 m as well as to examine and sample the broader stratigraphic context of the structure. Internal and background samples should be taken horizon by horizon at say 5 m or 10 m intervals, or arbitrary spit by spit, especially sample blocks for micromorphology and small bulk samples for geo-chemistry, but also large bulk samples for macro-botanical analysis. This type of approach was employed for example at the early Viking period trading hamlet site of Kaupang in Norway (Milek and French 2007, fig. 15.1; Skyre 2007) (Fig. 51). There the long axis of the structure was used as an arbitrary section line, with samples taken at 1/2 m intervals along its length. This type of sampling strategy may also be used if you were digging a long or round barrow in alternate quadrants and sampling the buried soil along each section axis (French 1994).

Alternatively, the third kind of sampling methodology involves superimposing a systematic 1 m grid over the whole internal/external area of the structure (Figs 47 and 50). The intention then would be to conventionally dig every other metre square in a 'checker-board' pattern to discriminate the stratigraphy, create four mini-sections for sampling through the post-floor and floor deposits, with artefact and faunal material retrieval as normal. Some good examples of this type of systematic gridded testing include the investigation of a Bronze Age riverside settlement in the Snail valley (Gdaniec *et al*. 2007, front cover), the Mesolithic–Neolithic old land surface and buried soil on the Godwin Ridge at Over (see Fig. 17) (Evans *et al*. in prep.), and a late Neolithic house structure at Saar in Bahrain (see Chapter 5 below). The mini-section baulks thus created can be used as sample stations for block micromorphology samples and small bulk samples for basic physical and geo-chemical analyses by context by depth. These generally comprise the analysis of pH, loss-on-ignition for organic carbon, magnetic susceptibility for detecting the presence/absence of burning, phosphates and multi-element geo-chemistry (after Allen and MacPhail 1987; Avery and Bascomb 1974; Bethell and White 1989; Canti 1995; Clark 1996; Crowther and Barker 1995; Wilson *et al*. 2005; 2008). If for example these samples were taken at the mid-point of each mini-section in each metre square, no set of samples would be more than about 50 cm apart, thus providing excellent sample replicability. This technique also allows the excavator to use the intervening one metre squares for bulk wet or dry sieving as appropriate for the recovery of artefacts, faunal remains, charcoal and uncharred plant remains, for example, as well as larger bulk samples for macro-botanical and faunal data recovery, by stratigraphic horizon/context.

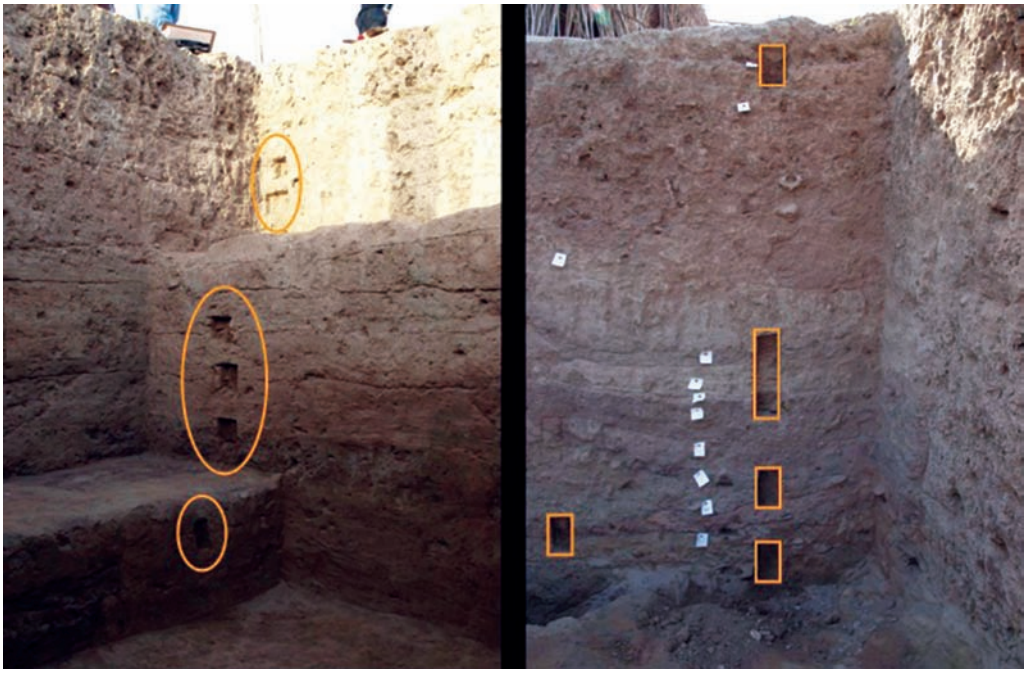


Fig. 46. Judgemental block sampling for micromorphology at the Masadpur I tell site in north-west India which is targeting the main horizon units and their transitions (S. Neogi)

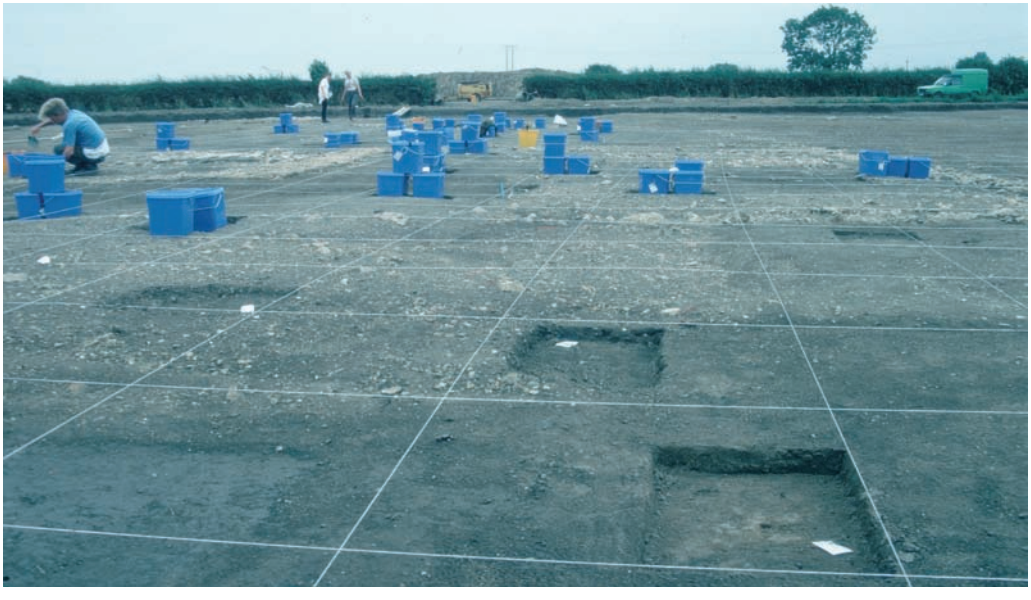


Fig. 47. Systematic metre-gridded sampling strategy of a Roman villa site with in situ *floor deposits at West Deeping, Lincolnshire, England (C. French)*

Multi-element analysis using inductively coupled plasma-mass spectrometry or atomic emission spectroscopy (ICP-MS or ICP-AES) determines the frequency of up to 35 elements, but only a much smaller suite of elements is usually considered reflective of human activities associated with agricultural, settlement and industrial practices in soils. These usually include barium, calcium, phosphorus, strontium, zinc and copper, whose accumulation is most likely associated with bone and charcoal in settlements (Wilson *et al*. 2008), with zinc known to be limited by phosphate with increasing pH (Cresser *et al*. 1998). Alternatively a microprobe or scanning electron microscopy energy-dispersive x-ray analysis (or SEM-EDX) may be used as other ways of quantifying similar elements in soils/sediments. Although the interpretation of variable frequencies of elements may be frought with taphonomic and interpretative problems, the smaller suite of elements does often reflect human activities such as middening and soil enhancement. For example, multi-element analysis has been successfully used to examine land management practices in the later Neolithic and Bronze Age of Orkney (Simpson 1997; 1998; Simpson *et al*. 2006; Hamlet 2014) and to aid the interpretation of structural space, such as at the Crossiecrown late Neolithic settlement in Orkney (Jones *et al*. 2010) and a more recent historical habitation site on Skye (Entwistle *et al*. 2000). It has also been used to investigate the composition of specific aggregates or lenses in soils/sediments (Macphail and Goldberg 2000), as well as the presence of heavy metals in soils, whether created by metalwork production or the waste from early mining activities (Mighall *et al*. 2002).

Needless to say, these sampling exercises for micromorphology and geo-chemistry/multi-element analyses will soon generate a lot of samples and specialist's time, especially if a one metre sample interval is used on a structure of any size. This luxury of multiple sets of samples taken on a one metre systematic grid may be possible on a research-driven excavation project, but in a rescue situation and even in a research project, this best case scenario may often have to be tailored by more practical judgements and cost/time limitations, and by the scope and nature of the primary questions that need to be addressed. In the published case studies following, a range of possible sampling strategies is set out with some summaries of the nature and implications of the geoarchaeological studies undertaken.

5. Examples of fieldwork strategies and sampling applications for investigating settlements

Saar, Bahrain

At one of the house structures at the late Neolithic settlement site of Saar in Bahrain (Killick and Moon 2005), a detailed sampling strategy was used to thoroughly and systematically investigate the multiple fine floor and occupation and post-depositional deposits present across the three rooms in the structure (Matthews *et al*. 1997a; Matthews and French 2005) (Figs 48 and 49). This was made easier by the extant height of walls upstanding (up to 1 m) with stone internal wall divisions and clear entranceways, as well as the structure being largely infilled by blown sand deposits. Once the wind-blown sand and a few later squatter type occupation deposits had been removed to reveal the *in situ* archaeological levels, then the interior rooms of House 205 were gridded out in 1m squares for excavation, recording and sampling (Matthews *et al*. 1997a, pl. 5). The conventionally excavated alternate metre squares immediately revealed a complicated and variable stratigraphy that was then block sampled for micromorphological analysis at 50/100 cm intervals from the available section faces. If this house was being sampled today, small bulk samples would also have been taken at similar intervals from the identifiable floor levels in each square metre section face for geo-chemical and multi-element analyses as well (but in 1993 the use of this technique was not common-place). The material in the intervening grid squares was then used for conventional dry sieving to examine the range and concentrations of artefact fragments and bioarchaeological remains included fish bone and charred/uncharred plant remains, in this case with 100% sampling and recovery.

The micromorphological analysis revealed much internal variation (Fig. 49) (Matthews *et al*. 1997a, 297). For example, the unoriented and heterogeneous calcareous silty clay aggregates observed in the entranceways were trampled, and the walkways in the central area of the house exhibited thick, homogeneous, trampled zones with much finely fragmented organic debris incorporated. In contrast, the small room had evidence of fine plaster floors, partly disturbed and fragmented by trampling, and an horizon of sandy silt with incorporated fine anthropogenic debris above. There were fine layers of water-splashed deposits and sand in front of the plaster basins, and lenses of date palm ash, fish bone fragments, fish scales, salts and sand had accumulated in front of the hearth (*ibid*., pl. 6). In the back courtyard, there were a number of spatially discrete micro-

Fig. 48. View of the excavations of a late Neolithic house at Saar, Bahrain (C. French)

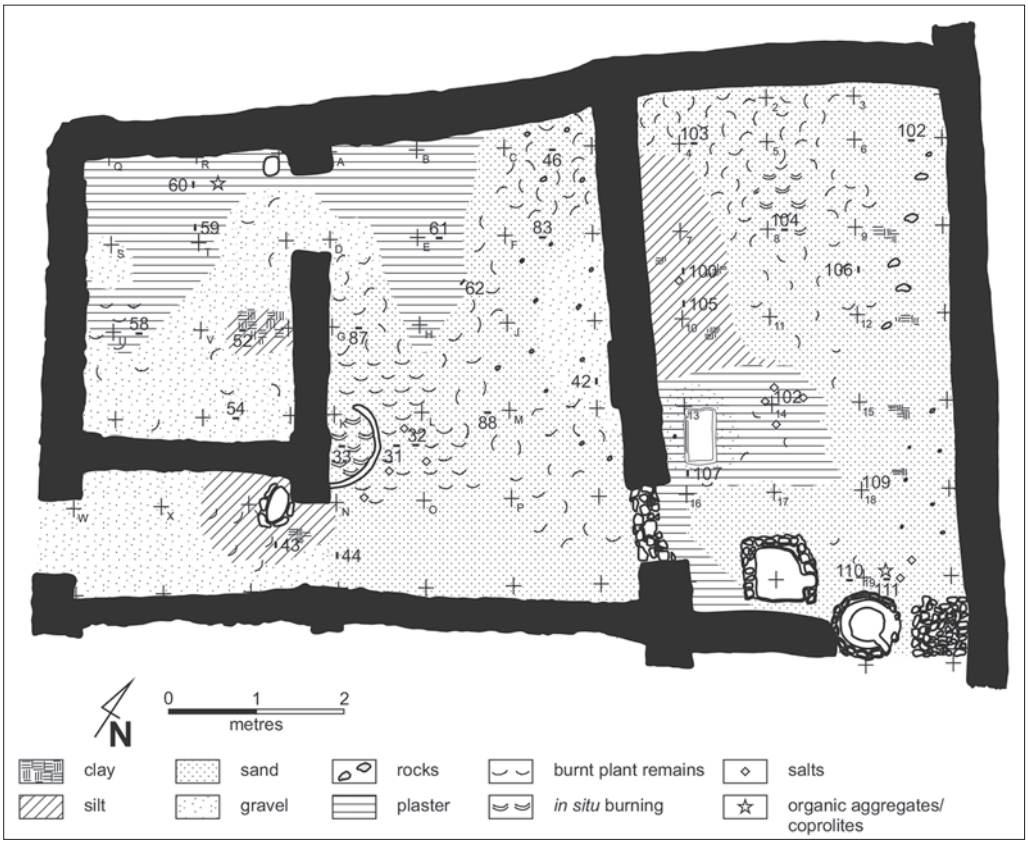


Fig. 49. Suggested use of space in a late Neolithic house at Saar (adapted from Matthews et al. *1997, fig. 2)*

stratigraphic sequences with coarse wind-blown sand deposits in one corner. This data was then combined with the artefactual and sieve-derived micro-artefactual data in a schematic fashion (Matthews *et al.* 1997a, fig. 2) to indicate possible uses of space within the house. For example, the back courtyard may have been used for a range of activities such as low temperature burning, food processing, dumping of refuse and perhaps the tethering of a herbivore, whereas the central large room was largely plastered but also exhibited evidence of *in situ* burning, burnt plant remains and fragmented bone and shell, possibly associated with food preparation, all of which was heavily trampled.

Fig. 50. Plots 3A/B of the Viking longhouse at Kaupang, Norway, with the sample bags marking sample locations for multi-element analysis of the upper surface of the occupation deposits (C. French)

Fig. 51. Soil sampling strategy of a Viking longhouse at Kaupang, Norway (from Milek and French 2007, fig. 15.1)

Kaupang, Norway

The site at Saar provided an ideal sampling situation, but structures being excavated on archaeological sites are rarely as uni-dimensional and so undisturbed, so various other expedient compromise strategies usually need to be adopted. For example, at the *c*. AD 800 Viking trading hamlet of Kaupang in Norway (Milek and French 2007; Skre 2007), the situation was very different. The overburden on site was generally thin (<50 cm), but the site had been ploughed in modern times, a series of pipe trenches crossed the site diagonally, and only one complete rectilinear structure was excavated in its entirety (see below). This early Viking period urban settlement at Kaupang is situated on the shores of the Viksfjord at the southern end of Vestfold in southern Norway. As the first urban settlement in Norway, and as a regional centre for craft production and trade in the 9th and 10th centuries AD, the site is of unique importance for the understanding of the social and economic history of early Viking-age Scandinavia (Skre 2007). Some of the key research issues in this area included how the urban settlement had developed, and how different activities related to craft production, trade, and urban living had been organised (*ibid*.).

As the excavations proceeded, it quickly became clear that the ability of the excavators to detect compacted surfaces was inhibited by the mainly black colour and coarse, sandy texture of the deposits, making floor levels hard to delimit, and the interpretation of the form and functions of the buildings also very difficult using conventional archaeological excavation approaches. In addition, no soils were visible in the field below the Viking occupation deposits, which raised questions about the environmental conditions on the site prior to the establishment of the urban settlement, and the nature of the earliest phase of settlement. Variability in the preservation of artefacts and archaeological stratigraphy also raised many concerns about the complex post-depositional processes that had potentially affected the site. It was obviously vital to understand these processes, and to pay them due consideration when drawing archaeological interpretations.

Accordingly, a programme of soil and sediment analysis was integrated into the project research design to tackle these questions as well as the interpretative and taphonomic concerns and problems. A broad suite of analytical techniques was applied, especially in the first assessment phase of the geoarchaeology programme, when the widest possible dataset was needed to characterise the depositional and post-depositional processes that had been prevalent on the site. This included sampling and analysis for pH, electrical conductivity, magnetic susceptibility, loss-on-ignition, elemental composition, and soil micromorphology (Milek and French 2007).

Once the ploughsoil overburden had been removed and the upper surface of the occupation deposits had been exposed, the whole area of plots 3A/B were sampled on a one metre grid for multi-element analysis (Fig. 50). Subsequently, more detailed analyses of the buildings in plots 3A/B, the midden, the pathway, and the harbour area concentrated on the use of micromorphology because of its unique ability to provide information about the original composition and mode of formation of the sediments prior to their alteration by post-depositional processes. Although the occupation deposits and floor deposits of plots 3A/B were all wet sieved systematically on a 1 m grid basis, the samples for geo-chemical and micromorphological analyses were taken

from three transects, a main long transect down the long centre-line of the structure aligned on its two hearths, and two transects at right angles to this one through each hearth area (Fig. 51). These micromorphological and multi-element samples were taken through no more than about 30 cm of the multiple floor and occupation deposits at one metre intervals, but in terms of processing and analysis only every second sample set was used.

Geo-chemical and micromorphological analyses identified a whole range of site formation processes, partially explaining the blurring of horizon boundaries (Milek and French 2007). Of these, bioturbation by soil fauna and the leaching of calcium and phosphorus had had the greatest effect on the preservation of the anthropogenic sediments. Nonetheless, it was often still possible in thin section to gain an understanding of the original composition and organisation of the sediments prior to their alteration by post-depositional processes. For example, although the calcareous component of wood ash had largely been leached away, it was still possible to identify those sediments that were originally composed of hearth waste as there were concentrations of minute fragments of wood charcoal, burnt bone, non-metallurgical slag and rare aggregates of preserved calcareous ash present in thin section.

Each of the buildings on plots 3A and 3B revealed two occupation phases in which the size and/or function of the structures were different (*ibid.*). This development was clearest in plot 3B, where two superimposed buildings were separated by a thin layer of fine gravel. Both buildings contained occupation deposits rich in hearth waste and organic matter, and therefore may have been places where cooking and food-consumption took place. Space in the later, larger building had been divided into three aisles: a central aisle with a clay hearth and an occupation surface that was especially rich in hearth waste, and two side aisles with deposits rich in decomposed plant matter. While the central aisle appeared to have been the main artery for foot traffic through the building, the side aisles had been less trampled, and were more likely to have functioned as either sitting, working, eating and sleeping areas.

In plot 3A, the two main floor levels of the two superimposed structures were separated by a thin, patchy sand layer (Milek and French 2007). The lower occupation phase was not associated with a hearth, but contained a very high concentration of plant matter including wood and bark tissues, thus possibly acting as a floor covering and/or reflecting a woodworking workshop. In contrast, the later building was larger, had a central hearth and probably contained two separate rooms. Around the central clay hearth and in the southeast end of the building, the floor surface might occasionally have been covered with grass mats, and exhibited repeated inputs of hearth and food refuse, organic matter and sand.

Crossiecrown, Orkney

This next example is a detailed geoarchaeological study of just one well defined settlement structure from Neolithic Orkney. A combination of sample strategies was used: systematic gridded samples for geo-chemical and multi-element analyses and more judgementally taken micromorphologcal samples, but which nonetheless gave good

spatial coverage across the interior of the structure. In addition, micromorphological samples were taken from the immediate vicinity of this site and another near adjacent site of similar date at Stonehall Farm (French forthcoming b). The late Neolithic (*c*. 3000 cal BC) settlement site of Crossiecrown is situated just to the east of Stonehall and Wideford Neolithic settlements, and to the north of Wideford Hill and Quanterness Neolithic chambered tombs on the Mainland of Orkney (Jones *et al*. 2010). The stone-built House 1 was exceptionally well preserved, and building on the earlier work at Barnhouse using magnetic susceptibility and phosphate surveys and soil micromorphological analysis (Richards 2005; Challands *et al*. 2005, 208; French 2005) and the development of geo-chemical applications to archaeological structures in Scotland (Entwistle *et al.* 2000; Oonk *et al.* 2009; Wilson *et al*. 2005; 2008), it was decided to apply these developmental archaeological science studies in a systematic fashion to this individual structure in some detail.

Prior to any excavation or sampling the whole area was subjected to a magnetometer survey. Once the turf/topsoil had been removed to reveal the thin (<10 cm) surviving floor deposits, a one metre grid and two cross-baulks were laid out over the structure (Jones *et al*. 2010, fig. 4). Samples for magnetic susceptibility, phosphate and multi-element analyses were taken at up to five locations in each metre square. Intact blocks for soil micromorphological analysis were taken on a less systematic basis, but at 15 sample stations located approximately on a checkerboard pattern at 1–2 m across the interior floor deposits of the structure.

The micromorphological analysis recognised a number of different floor deposit types in different spatial loci beneath secondary midden accumulations (French in Jones *et al*. 2010, 42–3). These ranged from areas of hard-packed silty clay to sandy loam surfaces, to calcitic ash directly on the bedrock, to multiple, finely bedded and probably trampled laminae of organic refuse indicative of successive phases of use and accumulation, and possibly even organic floor coverings. Discrete enhanced areas were present in the magnetic susceptibility results around the hearth, and for phosphate in one recess and in the entranceway (Jones *et al*. 2010). Two major and several minor clusters of elements were apparent with demonstrable small-scale variability. For example, different groupings of elements concentrated around the entranceway (i.e. P, Cu, Ba), the drains (i.e. Ca, P, Sr, Zn), around the hearth (i.e. Ca, Fe, P) and recesses (i.e. Pb), as well as discrete sets of different element anomalies around the hearth. When these groupings were considered with respect to the distribution of stone tools within the structure, the activity focus appears to lie in the eastern part of the house. This area corresponds with the stone boxes and pits and therefore may represent stored tools for example, and indeed stone tools were found close to and north of the hearth. In contrast, the waste zone, including ash from the hearth, is found in the southern part of the house near the drain.

Midden material soon accumulated on these earthen floor surfaces and fine elements of this was commonly reworked into the upper surface of the glacial till substrate below. Most of the post-floor sequence deposits involved the accumulation of humic soil and midden material derived from the fine debris of human living. The proximity of many of these sequences to the modern ground surface inevitably meant that there was a fair degree of post-depositional mixing of later deposits, but it nonetheless confirms that these settlement and midden areas were subsequently highly sought after for arable

activities. These soils were effectively amended and enhanced, making an excellent nutrient-rich tilth for a good crop growth from Bronze Age times on (cf. Simpson 1997; 1998; Guttman *et al*. 2004). In some cases these midden deposits are capped by a second floor level, also composed of either clay, ash or micro-layers of organic matter, possibly deliberately laid.

There is now a large number of comparable geoarchaeological studies of prehistoric floors and 'dark earth' type deposits from several sites in Orkney. Intensive geoarchaeological studies at Tofts Ness on Sanday (Simpson 1998; Simpson *et al*. 2006), Skara Bare (Simpson *et al*. 2006), the Links of Noltland on Westray (Hamlet 2014) and the Knowes of Trotty (McKenzie 2007), for example, have also shown that settlement-derived 'dark earth' type highly organic midden deposits have been used as in-fills of walls, floor preparation or foundation layers and subsequently for arable agricultural activities as fertiliser and to create organic topsoils, not just in midden dumps. In addition, there have been lipid bio-marker and stable isotope studies undertaken to investigate the use of manure and early land management techniques (Simpson *et al*. 1999a; 1999b). These complementary studies have demonstrated the extreme importance of managing settlement rubbish as a midden in the later Neolithic period, and utilising that same material for a whole variety of uses in and around the settlement and subsequently for providing sustainable arable soils throughout later prehistoric times.

Thus this study has been a useful methodological experiment involving two scales of data recovery, both an extensive wider view around the house from the geophysical, magnetic susceptibility and phosphate surveys, and internally within the structure with magnetic susceptibility, multi-element and micromorphological data. Importantly the results have given possible suggestions as to the differing uses of internal space and the development of the settlement site and the subsequent agricultural landscape.

6. Integration: Sampling and methods combinations

The best case scenario is to investigate buried soils and surfaces on a wide spatial scale in the field, preferably associated with an extensively well-studied and well-dated archaeological record. It is often also advantageous to have a variety of dedicated field and laboratory experimental data as well as ethnographic analogues to gain ideas about specific processes, activities and time scales involved (Fig. 52). Excellent examples of this type of experimental study are Helen Lewis's (1998; 2002; 2012) work on the recognition of ancient tillage practices from the soil, Richard Macphail's work with Gill Cruise and John Crowther at the experimental earthwork site of Overton Down (Crowther *et al.* 1996; Macphail and Cruise 1996), Canti and Linford's (2000) study of burnt soils, Boivin's (2000) study of replastered floors in Rajasthan, and studies by Goodman-Elgar (2008) and Friesem *et al*. (2011) of mud-brick disintegration on Bolivian Andean and Israeli tell sites, respectively. In addition, ethnographic and experimental soil analytical studies of compacted earthen floors in experimental round houses in southern England and Denmark (Banerjea *et al*. 2015), threshing floors in Israel (Shahack-Gross *et al*. 2009) and the character of herbivorous livestock dung (Shahack-Gross 2011) for example, can give us additional ways of interpreting and verifying the signatures that are seen in soil thin sections or in geo-chemical results.

What techniques are best and most informative to use? Several good papers have been written on the holistic approach that is necessary to carry out good archaeological soil investigations (Canti 1995; Barham and Macphail 1995; Goldberg and Macphail 2006, 299ff), and obviously one must be as flexible and adaptable and 'cut the cloth' to some degree to suit the questions, time and money available. Ideally as many techniques as possible should be used, including soil analytical techniques and other palaeo-environmental techniques such as palynological and molluscan analyses, as well as an array of appropriate dating techniques and GIS terrain map base templates to portray and interrogate different types and levels of data.

Good field description and assessment is the first and most crucial step. This entails first walking around the whole site or survey area with the archaeologist in charge of the project and fieldwork (and preferably with as many other specialists involved in the project as possible), looking at all available exposures/sections, as well as going off-site if at all possible to look at profile change away from the direct influence of human occupation. In an ideal world one can take up to several weeks' time to become really

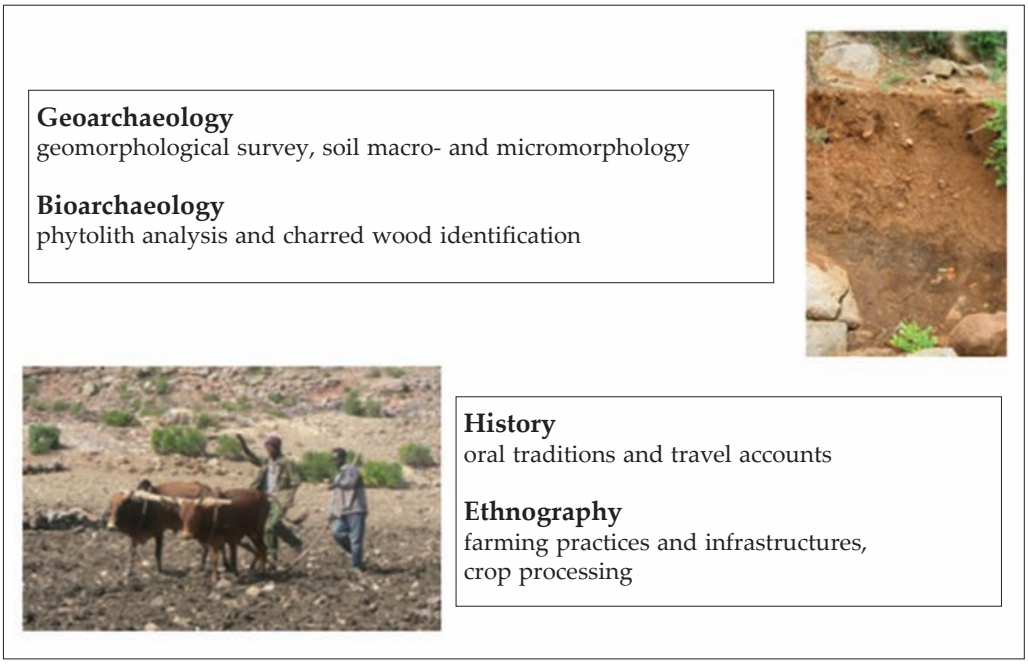


Fig. 52. A framework for integrative research utilising geoarchaeological, bioarchaeological, historical and ethnological data (F. Sulas)

familiar with the landscape that is being investigated. 'Breezing in' for a few hours as the specialist can work if it is single discrete site, but it is often unsatisfactory and certainly would not do if one were trying to get to grips with a landscape.

Once decisions have been made as to which are the best and most representative sections on and off-site to sample, and at what intervals will the site's profiles be described and sampled, it then becomes a question of the level of description, the relevant techniques to use, and the sample intervals necessary. No one can tell you the absolute 'right' answer to this, it is a matter of individual judgement in the particular locational circumstances in consultation with the project and archaeologist's aims and questions. Effectively, the more you see, the better you get at this part of the process. There is no substitute for time in the field. Initial assessment work should be done by the most able and qualified person who can be persuaded to come out to the site, not normally the novice. Initially, I would rather look at an uncleaned section or one that has seen a month's weathering than one that has just been cleaned for photography, as it often gives a much better idea of soil structure and horizon boundaries. After photographing and drawing a cleaned section to scale with appropriate layer/horizon descriptions, also examine the section opposite if there is one. This is now the time and place to describe colour and the exact nature of the contacts/boundaries visible between horizons. Sometimes there is little need to do more than this at this stage of the assessment and description process, especially when a site is heavily damaged

or truncated by ploughing, or it is the first preliminary evaluation stage. Of utmost importance from this field assessment exercise is that you know why and what samples you want to take, so that you can set out a costed timetable for processing and analysing them in conjunction with the appropriate archaeologists and specialists, or they will fester in a heap somewhere for some eventual but perhaps unlikely analysis.

There are no absolute rules for soil sampling. If it is a deep linear feature such as a palaeo-channel, it is best to take a set of overlapping monolith tins throughout the whole stratigraphic sequence and then sub-sample these back in the laboratory as necessary, but say specifically for pollen, diatoms and particle size analysis for example (see Fig. 45). For buried soils and occupation sequences, a combination of monoliths, individual blocks and small bulk samples by depth, horizon or stratigraphic unit are appropriate (see Fig. 46), or by horizon across a spatially exposed lateral area such as a floor or occupation surface (Figs 47, 50 and 55). Intact blocks of soil or sediment are required for soil micromorphology, x-radiography, energy dispersive x-ray analysis, bulk density, plasticity and shear strength. Small but loose bulk samples (i.e. <0.2 kg) are suitable for most other soil analytical techniques (Hesse 1971). Large (1–2 kg) bulk samples are needed for molluscan samples, and at least 60 litres (volume) for macro-botanical and insect samples. Every sample must be measured in and related to a datum point on the site, and its position marked on a section and site plan. Also, it is best if you are sampling for other sets of analyses at the same time such as pollen and molluscs, and that the sample sets are taken side by side in relation to the stratigraphy, preferably by both specialists concerned. Close interval or contiguous sampling, both as blocks and small bulk samples, is necessary for floors, old land surfaces and/or buried soils, as well as primary feature fills. But if there are only a few thick horizons present, block and small bulk samples samples either taken across and/or above and below boundaries are usually sufficient, and/or in combination with a series of spot samples taken from the main layers/horizons (see Fig. 46). Block samples for micromorphological analysis may also be taken across the upper and lower zones of feature cuts to gather ideas about the implements used and infilling factors, as well as from the modern topsoil or overburden and the weathered B/C substrate for comparative purposes.

How many profiles should one sample? Again this will largely depend on research questions/priorities, money and time, but the aim should be to take a representative series of samples through the main stratigraphic horizons present both across and off a site to gain an idea of lateral, spatial and vertical variation. For example, in a best case scenario at the Roman villa at West Deeping in Lincolnshire (see Fig. 47) and the later Neolithic houses at Saar in Bahrain (see Fig. 48), block samples for micromorphology were taken from every section face of each metre square in an alternate 'checker-board' fashion so that no sample was more than 50 cm apart, with the intervening metre square then bulk sampled and dry seived for artefactual, faunal and botanical remains (Matthews 2003; 2005; 2010; Matthews *et al.* 1996; 1997a; 1997b). In another case, the buried soil beneath a Bronze Age barrow mound could be sampled at three different loci about 10 m apart for micromorphology, particle size analysis and a suite of geo-chemical analyses, and one or two profiles taken from outside the mound for comparative purposes, bulk samples were taken from alternate metre squares from the old land surface beneath the mound and from the primary ditch/pit feature fills for sieving for

macro-botanical and artefactual remains (i.e. Deeping St Nicholas barrow; French 1994). At the other extreme, there is often a thin, probably truncated, buried soil surviving on an enigmatic prehistoric site where it was hard to justify taking more than one profile for micromorphology given the post-depositional disturbance and destruction of the horizon and site (i.e. Maxey in the lower Welland valley of Cambridgeshire; Pryor and French 1985; Pryor 1985), but the whole surviving thickness of the buried soil would be systematically excavated by hand to recover the artefact and faunal remains.

What geoarchaeological and soil analytical techniques are best to use? There is no one single best type of method, rather it is a question of deciding what is the nature of preservation of soils on site and which suite of methods is appropriate to the site, the questions being asked, and unfortunately, the funds and time-frame available for analysis. A combination of geoarchaeological techniques is usually the best approach (see Table 2), with some kind of sampling strategy being employed. Also, the approach often depends on the type of archaeological deposit being sampled – is it feature fill, floor or occupation sequence, midden deposit, old land surface and/or buried soil? Typically, buried soils on archaeological sites are often poorly preserved in terms of shallow burial conditions and only feature fills are available for bulk sampling. Consequently a series of representative small bulk samples should be taken on a systematic basis from the fills of a suite of features of different types and ages across the site for physical characterisation using particle size, pH and organic matter content analyses for example.

If the site was well buried and sealed with buried soils and/or had *in situ* floors or archaeological surfaces available, a combination of soil micromorphology block samples with accompanying small bulk samples taken for pH, magnetic susceptibility and phosphates and/or multi-element or scanning electron microscopy analysis (i.e. ICP-AES or SEM-EDX) could be appropriately taken on a systematic grid basis (Allen 1990; Allen and Macphail 1987; Canti 1995; Courty *et al*. 1989; Crowther 1997; Crowther and Barker 1995; Simpson 1997; Wilson *et al*. 2005; 2008). The latter techniques would allow the investigation of nutrient loadings across context groups on the site and the enrichment of anthropogenic sediments/soils with Mg, P, K, S and Ca for example to compare to the local geological and soil control samples. If there were certain features in the micromorphological analysis that required quantification such as the degree of compaction of a surface and identifying particular geo-chemical features, additional techniques such as multi-element (using ICP or SEM) analyses, micro-probe and/or x-ray techniques may be appropriate to employ (Acott *et al*. 1997; Adderley *et al*. 2006).

Many landscapes often present a combination of eroded and aggraded sediments, truncated surfaces and surviving fragments of buried soils. In this case, a combination of field recording with judgemental sampling for soil micromorphology (Murphy 1986), particle size analysis, pH and organic content (Hesse 1971; Avery and Bascomb 1974) could be the first line of sampling, with the possibility of taking further samples for a selection of other purposes such as heavy mineral analysis, bulk density, plasticity, shear strength, phosphate, iron and calcium carbonate analyses as appropriate (Avery and Bascomb 1974; Goudie 1990; Limbrey 1975; Shackley 1975; Smith and Atkinson 1975). At a later stage it might be necessary to examine a sub-set of samples by multi-element analysis (Oonk *et al*. 2009; Wilson *et al*. 2008) or x-ray fluorescence (XRF)

(English Heritage 2007) or scanning electron microscopy (SEM) and micro-probe analysis (Canti 1995; Mackereth 1965) or lipid biomarkers (Simpson *et al*. 1999a; 1999b) to gain a better idea of the elemental composition of some of the soil/sediment sources. This would ideally be in combination with a programme of targeted radiocarbon and optically stimulated luminescence dating (Aitken 1985; Grun 2001; Lang and Wagner 1996; Rees-Jones and Tite 1997) to gain an idea of the major periods of movement and stabilisation in the system.

7. Conclusions

I hope that this handbook will give some good ideas as to what is possible using a geoarchaeological perspective and approach given certain major landscape and/or site parameters. Pointers have been given as to how to sample both landscapes and settlement sites appropriately, at different scales and using different suites of complementary techniques. These are not to be seen as applying a recipe list to the type of site or landscape being investigated, but rather present a range of possibilities from a wide repertoire of available techniques. Not every question is answerable, but a good range of possibilities is given as to what can and should be done, and the types of results that could be forthcoming. Most soil analytical approaches have now been around for some time, but the combined use of soil micromorphology and various elemental component approaches are still developing in terms of application, interpretation and verification. Nonetheless, it is possible to take these soil methods and combine them with other types of archaeological, ethnographical and palaeo-environmental approaches to build holistic interpretative sequences of landscape change and settlement activities, which may have significant implications for the interpretation of people's activities in the past and in the present (Fig. 53).

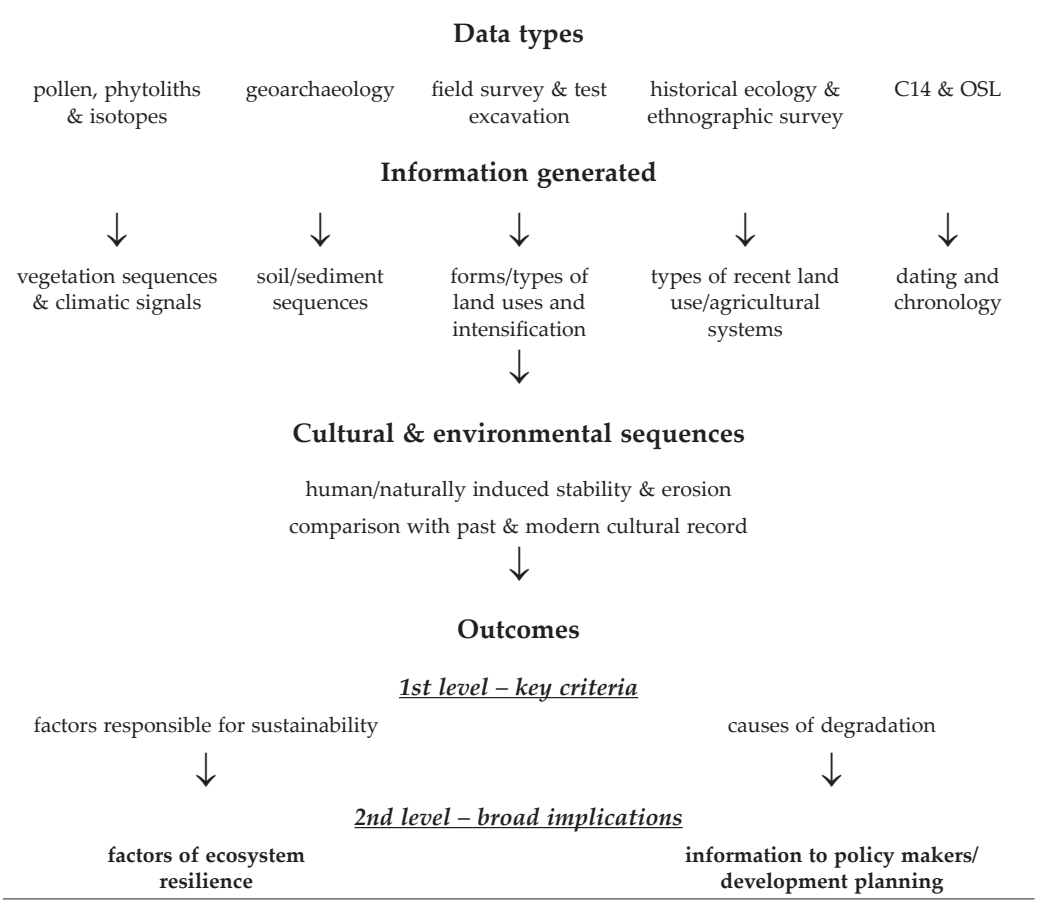

Data types
pollen, phytoliths & isotopes
geoarchaeology
field survey & test excavation
historical ecology & ethnographic survey
C14 & OSL
Information generated
vegetation sequences & climatic signals
soil/sediment sequences
forms/types of land uses and intensification
types of recent land use/agricultural systems
dating and chronology
Cultural & environmental sequences
human/naturally induced stability & erosion
comparison with past & modern cultural record
Outcomes
1st level – key criteria
factors responsible for sustainability
causes of degradation
2nd level – broad implications
factors of ecosystem resilience
information to policy makers/ development planning

Fig. 53. Flow chart of geoarchaeological and palaeo-environmental data required to model sequences of landscape change and provide data with wider implications pertaining to sustainability and climate change (F. Sulas and C. French)

Appendix 1
Bulk sample methodologies

An excellent guide to several of the procedures set out below may be found in the *Soil Survey Laboratory Methods* (Avery and Bascomb 1974) handbook, and on the web-site of the Physical Geography Laboratory of the Department of Geography, University of Cambridge (www.geog.cam.ac.uk/facilities/laboratories/techniques/psd.html).

Or initial sample preparation, all samples should be air-dried for one week and oven-dried at *c*. 30–35°C for one day, then dry-sieved to remove constituents over 2 mm in size and pulverised using a mortar and pestle.

pH

The pH of a soil solution is a measure of the concentration of hydrogen ions and is a proxy measure for the acidity/alkalinity of the soil or sediment (FitzPatrick 1986, 109). Human activity on a site can influence the pH level through the addition of certain materials, such as ash and plant matter. Moreover, the pH of a deposit can affect the stability of certain elements within a deposit, such as phosphorus becoming prone to leaching in more acidic conditions.

pH is tested using 10 g of sediment placed in a 50 ml plastic beaker and mixed with 25 ml de-ionised water in order to achieve a 1 to 2.5 soil:water suspension. The sample and water are vigorously mixed with a glass rod in order to form a slurry and the pH of the slurry is measured using an electronic pH meter (Hanna). The pH meter is calibrated using pH 4 or 7 calibration fluid (as appropriate). Three readings are taken per sample and averaged. After each reading the electrodes are rinsed in de-ionised water in order to prevent the cross-contamination of samples.

When dealing with wetland and/or waterlogged contexts of the samples, it may also be appropriate to conduct electrical conductivity (EC), redox (Eh) and dissolved oxygen (DO_2) tests at this stage (Caple *et al*. 1997; Holden *et al*. 2006). EC and Eh are also tested using 10 g of sediment placed in a 50 ml plastic beaker and mixed with 25ml de-ionised water in order to achieve a 1 to 2.5 soil:water suspension. After 1 minute, stir again and insert the conductivity and redox probes, and take one reading from each. For conductivity, note the water temperature, and correct readings as follows (e.g. 15C × 1.247; 16C × 1.218; 17C × 1.189; 18C × 1.163; 18.5C × 1.15; 19C × 1.136; 20C × 1.125).

Loss-on-ignition

The relative proportions of organic and inorganic carbon in soil or sediment can be estimated by the weight lost on heating to 550ºC and 950ºC (Avery and Bascomb 1974), respectively. Loss-on-ignition analysis uses 8–10 g of sediment (sampled using calibrated 1 cm^3 brass volumetric sampler) transferred to crucibles of known weight and heated in a muffle furnace for 6 hours at 105ºC to remove all water. After weighing, the samples are heated for 6 hours at 550ºC and reweighed at 105ºC. The samples are then returned to the oven, heated for 6 hours at 950ºC, and weighed again at 105ºC. The difference between the oven-dried weight and the weight recorded after heating to 550ºC, divided by the oven-dry weight of each sample, gives a proxy measurement for the percentage of organic matter in the soil or sediment. The difference between the weight recorded after 550ºC and the weight recorded after 950ºC, divided by the oven-dried weight of each sample, gives a proxy measurement for the percentage of inorganic carbon in the sample.

Magnetic susceptibility

Magnetic susceptibility is a measure of the ability of a soil or sediment to become magnetised when it is placed in a magnetic field and is a proxy measure for the metal content (Clark 1996, 90ff). Since high temperatures can cause iron in the soil to be converted to magnetite, enhanced magnetic susceptibility values in archaeological sediments permit the estimation of concentrations of burnt sediment.

Magnetic susceptibility analysis is conducted using 1 cm^3 plastic pots which are filled with the powdered sample and weighed in order to obtain the bulk density of the sample. Magnetic susceptibility measurements are taken using Bartington Instruments MS3 2B magnetic susceptibility meter with a low frequency sensor. The MS3 2B System operates by generating a low frequency, low intensity magnetic field around the sensor. When sample material is placed near the sensor, the resulting change in this field is sensed by the system and converted to magnetic susceptibility readings for both positive and negative values, to a resolution of 2×10^{-6} SI units.

Phosphorus (or phosphate) content

Phosphorus analysis (as an equivalent to total phosphate content) can be used to locate areas with increased organic content caused by human activity (Bethell and Mate 1989; Crowther 1997; Holliday and Gartner 2007). This is based on the consistent generation of organic debris as a result of human agency. Phosphorus is one of the main building blocks for all forms of organic matter, and upon its decomposition it is released and becomes fixed in the soil.

Total phosphorus content analysis is performed using the 'molybdate blue' reaction where the depth of colour is proportional to the concentration of phosphorus. 1 g of sediment is added to 100 ml of distilled water and the resultant soil:water suspension is filtered through a paper cone. 10 ml of this solution is then mixed with ten drops of

reagent A (ammonium molybdate in sulphuric acid) and a sachet of reagent B (sodium metabisulfite). The solution is placed in Hanna Instruments colorimeter, where light shining through a standard cell produces an electrical current proportional to the light attenuation. Results are usually expressed in mg/l or as ppm.

Multi-element analysis by inductively coupled plasma atomic emission spectroscopy (ICP-AES)

Inductively coupled plasma atomic emission spectroscopy measures the relative concentrations of up to 35 elements in the soil or sediment using a nitric acid–aqua regia digestion system. The samples may be sent away to a commercial laboratory such as ALS Global, or a more limited number of samples processed in-house for fewer elements. The latter include the elements most relevant to archaeological research such as barium (Ba), calcium (Ca), iron (Fe), potassium (K), manganese (Mn), phosphorus (P), strontium (Sr), and zinc (Zn) (Entwistle *et al*. 1998; Wilson *et al.* 2005; 2008; Oonk *et al*. 2009).

Multi-element analysis is conducted using a sub-sample of 1 cm^3 of soil/sediment. The elements in the samples were then leached using a nitric acid–aqua regia digestion system. The sediment is mixed with 6 ml of HCL and 2 ml of HNO_3 and the solution is left to react at room temperature for 30 minutes, then heated to temperatures of 50ºC, 65ºC, 75ºC and 95ºC for 30 minutes. The resultant solution is diluted with 40–45 ml of polished water. A Perkin-Elmer ICP-OES analyser is used to measure the concentrations of several elements (i.e. Ba, Ca, Fe, K, Mn, P, Sr and Zn are some of the most commonly analysed with respect to reflecting human waste and refuse making activities). The machine uses an ICP source to dissociate samples into their constituent atoms or ions, exciting them to a level where they emit light of a characteristic wavelength. The light resulting from the excitation of the elements in the sediment is then collected by an atomic emission spectrometer, resolved into a spectrum of constituent wavelengths, measured for its intensity, and converted to an elemental concentration (ppm or %) by comparing it to calibrated standards.

Appendix 2
Sampling for soil/sediment micromorphological analysis

Essential materials

1) Role of cling film and/or paper towel
2) parcel-post packing tape
3) trowel and/or strong knife
4) optional containers to hold sample blocks: use Kubiena tins, or *c*. 5–8 cm square sectioned plastic downpipe, cut into *c*. 10–15 cm lengths, with one long side cut off using a hack saw; or plastic boxes; or old cardboard juice cartons; or tin-foil take-away/frozen food containers.

Field sampling technique

1) identify major horizons and/or horizon boundaries; draw and photograph sections;
2) sample either as a continuous set of blocks or as discrete blocks; i.e. with each block size as *c*. 10–12 cm tall by *c*. 5–6 cm wide/thick (see Figs 46, 54 and 57);
3) if possible, sample across all main layer/horizon/context boundaries;
4) cut out a vertical slot along the sides of the prospective soil block in order to fit the container from the section face; start wide and work your way in; place container over the prospective sample block; cut out from well behind the section face and block; once removed from the section and remembering which way is up, trim the sample monolith block down as necessary; if section is of a particularly sandy matrix, several attempts may have to be made to cut out an intact block – for these it is better to use more 'weathered/crusted' sections if available; blocks can also be carved out freehand if the textural matrix allows it;
5) wrap in cling film/paper towel and then in parcel or masking tape (Fig. 54);
6) label with site sample/context numbers; indicate by arrow with indelible marker which way is up;
7) pack for transport back to the lab in any receptacle, i.e. wooden or cardboard box, or suitcase, use newspapers/clothes for cushioning or any other suitable material. Note: it does not matter whether the samples dry out or not, but it is important to keep them as undisturbed as possible, and to always know which way is up.

Fig. 54. The author taking soil blocks for micromorphological analysis in the field at the prehistoric settlement site of Zecovi near Prijedor in Bosnia Herzegovina (T. Rajkovača)

8) if possible, take at least one small (one handful) loose soil sample (*c*. 200–400 g) to complement each soil block for physical/chemical analyses;
9) for importation into the UK, you will need to carry a copy of a DEFRA Soil Import License and letter of authority with you, and/or have a copy accompany the samples.

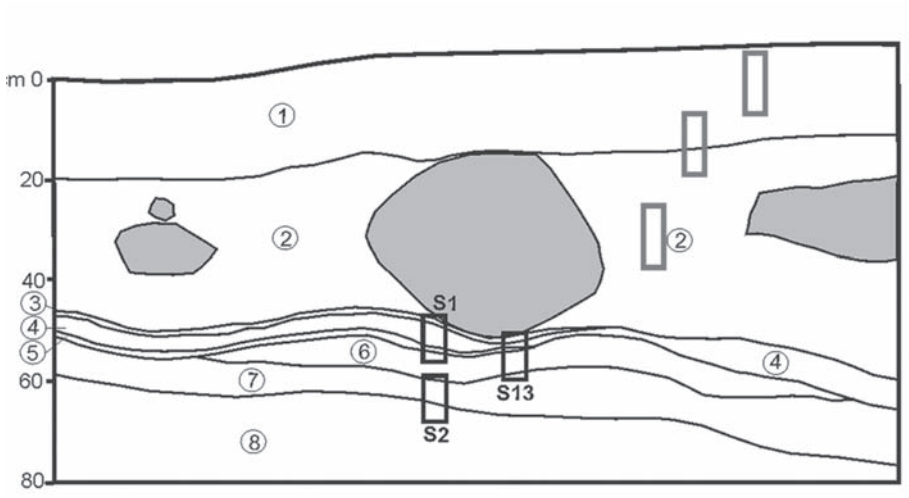
Sampling of *in situ* floors and occupation deposits

If you are presented with the upper surface of a floor or occupation deposit, you can also sample from this surface by pushing/cutting the sample tin in from above. This is best done on a systematic grid if possible, say at 50 cm or 100 cm intervals (Figs 47, 51 and 55). Take one small bulk sample with each undisturbed block. Number, plan and photograph the sample locations as appropriate. Once this is done, that spit of floor deposit (*c*. 5–6 cm) can be excavated conventionally, and if further floor deposits are present beneath, another series of samples can me taken, and so on.

Alternatively, the floor deposits may be dug in alternate quadrants (Fig. 56), thus leaving upstanding baulk sections which can then be used for micromorphology/small bulk sampling, again at 50 cm, 100 cm or 200 cm intervals as appropriate.

Fig. 55. Soil sampling on a systematic grid from an exposed floor level in an Hispanic period house at Sangayiaco in the upper Ica valley of Peru (C. French)

Fig. 56. Excavation in opposing quadrants of an Hispanic period house at Sangayiaco in the upper Ica valley (C. French)



1 Ap horizon; brown (10 YR 3/3) humic sandy loam

2 Buried Ap horizon; very dark brown (10 YR 2/2) humic medium to coarse sandy loam

3 Black (10 YR 2/1) humic coarse sand, with charcoal inclusions

4 Greyish brown (10 YR 4/2) silty sand

5 Black (10 YR 2/1) humic coarse sand, with charcoal inclusions

6 Pale grey brown silty sand (10 YR 5/3)

7 Black (10 YR 2/1) humic coarse sand and fine gravel, with charcoal inclusions

8 Dark yellow brown (10 YR 3/6) coarse sand and fine gravel, apparently cemented by iron oxides

Fig. 57. Schematic section drawing with micromorphology sample block locations marked by grey and black rectangles (C. French)

Appendix 3
A brief guide to making soil/sediment thin sections: from the field to finished slide using the Brot grinding system

with Tonko Rajkovača

Preparations for making thin sections

Samples are collected from the field, and brought to the laboratory if they are EU/UK soils, or directly to the DEFRA storeroom for non-EU soils under licence. The samples must be kept in plastic bags and within suitable sealed boxes.

UK/EU soils should be air-dried for at least 2–4 weeks, and oven dried for *c*. 24 hours at 30°C prior to impregnation. Non-EU soils should be put directly in the drying oven for *c*. 24–48 hours at 30°C prior to impregnation. The samples are then impregnated with polyester resin, and stored to cold-cure in a ventilated cabinet for about 1 month (see below). When the resin has set, the samples are moved to an oven to be hard-cured with heat (see below). After the blocks are cooled, they are then cut to a desired size for the next stage of thin section production (see below).

Major items of equipment include: one large ventilated cabinet, one large standing fume-cupboard, one fan-assisted standing oven, one vacuum chamber/oven, one perspex surround sawing unit, and a Brot thin-section multi-plate grinder.

Necessary additional control/safety measures

All products used in the production of thin sections are solvent based and flammable. Consequently it is laboratory policy that all chemical and resin preparation must be performed within a fume cupboard. The laboratory should have in place: chemical spillage kits, a fire-bin for flammable lab waste, a fire blanket and appropriate fire extinguishers. Immediate access to a First Aid Kit and Eyewash supplies should also be available.

Collection and drying of samples

Protective measures: All persons working with soil, sediment, or archaeological materials should wear a lab coat and use vinyl or nitrile gloves.

1. Soil, sediment, and/or archaeological samples are taken from the field and brought to the sample store.

For UK/EU soils:

2. UK/EU samples are placed in open trays or plastic boxes with appropriate labels, and cut open to reveal enough surface to allow air drying. Special care should be taken not to disturb the original composition and structure.
3. Site designations and section orientation/profile are checked on the blocks, and written on the outside of the containers. Arrows can be added as an indication of the top of the profile, and where the block should be cut for thin-sectioning.
4. The samples are then placed on the shelves in the lab for a period of up to a month to remove moisture before impregnation. If samples arrive from the field wet, water will have to be removed by acetone replacement (for which there is a separate protocol).
5. After a month, the samples are taken from the shelves and placed in the oven for a final drying period, starting at 30–35°C for 24–48 hours.
6. Any soil waste should be put directly into the appropriate waste bin for incineration.

For non-UK/non-EU soils:

7. The samples should be taken from the DEFRA licensed storeroom and put directly into the drying oven for 48 hours at 30–35°C in open plastic boxes prior to impregnation.
8. Any spillage of soil material should be swept up immediately and disposed of in the appropriate waste bin for incineration (along with all packaging materials). Disinfectant should be used to clean the spillage area, and all waste from this cleaning up operation put in a sealable plastic bag and then put in the appropriate waste bin for incineration.
9. The next step is impregnation.

Impregnation (Fig. 58)

Protective measures: All persons impregnating with resin must wear a lab coat and nitrile gloves, and work within the fume-cupboard. Safety glasses and face-masks must be worn as additional personal protection equipment when transferring samples to the vacuum chamber and the ventilated curing storage cupboard.

1. Place the soil blocks in 1 litre plastic ice-cream tubs and appropriately label the outside of the container, always remembering to note the correct orientation of the sample.
2. Impregnation mixes may vary dependant on the soil, sediment, and/or archaeological material type and structure. The standard mix for impregnation is 1800 ml of clear polyester casting resin, poured into a graduated plastic decanter, with 200 ml of acetone added to the resin to increase the viscosity (greater quantities of acetone (up to 400 ml) may be used if the sample is predominantly clay and/or silt dominated).
3. Add 1 ml of Methyl Ethyl Ketone (MEKP), the catalyst for hardening the resin, by pipette and mix thoroughly. There should be an immediate colour change from blue

Fig. 58. Impregnating soil blocks placed in ice cream tubs with the resin mix in the fume cupboard, with the first slices cut from impregnated blocks on the right (K. Boulden and T. Rajkovača)

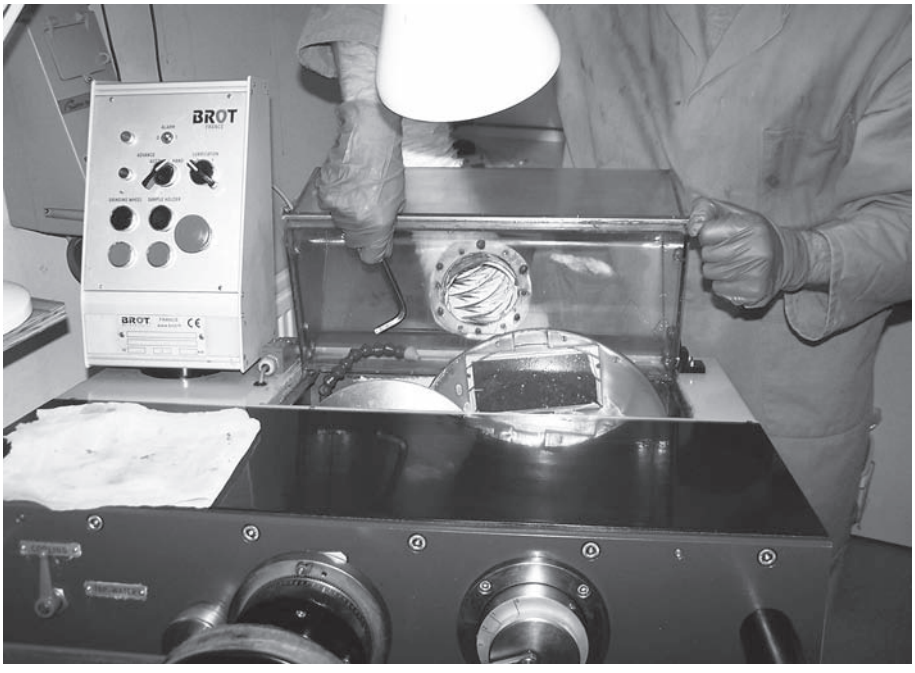


Fig. 59. The Brot thin sectioning machine showing a slide mounted in the holder plate ready to be ground (K. Boulden and T. Rajkovača)

to green. Any gloves that become contaminated with MEKP must be discarded into a sealed plastic bag, and new gloves put on to protect against potential chemical burn.

4. Check that all the air bubbles in the resin from mixing have settled out, and then slowly pour into the container, fully immersing the samples. The samples are left to infiltrate with resin by capillary rise for up to an hour in the fume-cupboard, topping up as necessary.
5. Transfer the samples in the resin mix to the vacuum chamber wearing a facemask and goggles. Slowly bring the vacuum to 12–28 mercury, or until bubbles can be seen, and leave the samples under pressure for an initial 24 hour period.
6. After 24 hours, a second resin mixture is prepared. After releasing the vacuum, take the samples from the chamber, place in the fume-cupboard, and 'top-up' with resin, and then place back into the vacuum chamber for a further 24 hour period, using the same vacuum pressure as before.
7. After the final vacuum, take the samples from the chamber and place in the ventilated curing storage cupboard for about 1 month or until the blocks have completely hardened.
8. When the samples have hardened, subject them to a final curing in the oven at *c*. 35–40°C for a *c*. 24–48 hours.
9. The next step is sawing the blocks using a diamond-bladed, water-lubricated band saw to produce a 3–4 mm thick slice for thin sectioning.

Thin sectioning (Fig. 59)

There are a number of different machines used for making thin sections. Traditionally, lapping plate systems have/are used, but at Cambridge we use a French Brot multi-plate grinding machine instead. There is a lengthy and specific protocol to follow for this type of thin section manufacture, which can be supplied on request. Essentially, the glass and a 4–5 mm thick slice from the block are both prepared for mounting by grinding one face absolutely flat using the Brot. Once this is done, a permanent bond of polished soil slice to the polished (now opaque) glass slide is made, then returned to the Brot and ground until about 30 μm remains. The thin section is then cleaned and cover-slipped, and is now ready for analysis under the polarising microscope. If any micro-probe work is required, do *not* cover-slip the slide.

Bibliography

*References starting with a * are essential texts*

AAREA Project. 2014–2019. 'The Archaeology of Agricultural Resilience in Eastern Africa.' http://www.york.ac.uk/archaeology/aarea-project.eu

Abate, T. 1992. Resource use in Konso. *Sociology Ethnology Bulletin* 1, 22–5

Acott, T. G., Cruise, G. M. and Macphail, R. I. 1997. Soil micromorphology and high resolution images. In Shoba, S., Gerasimova, M. and Miedema, R. (eds) *Soil Micromorphology: studies on soil diversity, diagnostics and dynamics*, 372–78. Moscow-Wagingen: International Soil Science Society

Adderley, W. P., Simpson, I. A. and Davidson, D. A. 2006. Historic landscape management: a validation of quantitative soil thin-section analyses. *Journal of Archaeological Science* 33, 320–34

Aitken, M. J. 1985. *Thermoluminescence Dating*. London: Academic Press

Allen, M. J. 1990. Magnetic susceptibility. In Bell 1990, 197–202

Allen, M. J. 1992. Products of erosion and the prehistoric land-use of the Wessex Chalk. In Bell, M. and Boardman, J. (eds) *Past and Present Soil Erosion*, 37–52, Oxford: Oxbow Monograph 22

Allen, M. J. 1995. Before Stonehenge, The environment sections. In Cleal *et al.* 1995, 4–5, 34, 41–65, 116–7, 168–9 & 332–4

Allen, M. J. 1997a. Environment and land-use: the economic development of the communities who built Stonehenge (an economy to support the stones). In Cunliffe, B. W. and Renfrew, A. C. (eds) *Science and Stonehenge,* 115–44. London: *Proceedings of the British Academy* 92

Allen, M. J. 1997b. Landscape, land-use and farming. In Smith, R. J. C., Healy, F., Allen, M. J., Morris, E. L., Barnes, I. and Woodward, P. J. *Excavations along the Route of the Dorchester By-pass, Dorset, 1986–8*, 166–84. Salisbury: Wessex Archaeology Report 11

Allen, M. J. 1998. A note on reconstructing the prehistoric landscape environment in Cranborne Chase: the Allen valley. *Proceedings of the Dorset Natural History and Archaeological Society* 120, 39–44

Allen, M. J. and Gardiner, J. 2009. If you go down to the woods today; a re-evaluation of the chalkand postglacial woodland; implications for prehistoric communities. In Allen, M. J., Sharples, N. and O'Connor, T. P. (eds), *Land and People; papers in memory of John G. Evans*, 49–66. London: Prehistoric Society Research Paper 2

Allen, M. J. and Green, M. 1998. The Fir Tree Field shaft: the archaeological potential of solution features in chalk. *Proceedings of the Dorset Natural History and Archaeological Society* 120, 25–38

Allen, M. J. and Macphail, R. I. 1987. Micromorphology and magnetic susceptibility studies: their combined role in interpreting archaeological soils and sediments. In Fedoroff, N., Bresson, L. M. and Courty, M-A. (eds) *Soil Micromorphology*, 669–76. Paris: Plaisir

Amborn, H. 1989. Agricultural intensification in the Burji-Konso cluster of southwestern Ethiopia. *Azania* 24, 71–83

Armour-Chelu, M. and Andrews, P. 1994. Some effects of bioturbation by earthworms (oligochaeta) on archaeological sites. *Journal of Archaeological Science* 21, 433–43

Avery, B. W. 1980. *Soil Classification of England and Wales*. Harpenden: Soil Survey Technical Monograph 14

Avery, B. W. and Bascomb, C. L. 1974. *Soil Survey Laboratory Methods*. Harpenden: Soil Survey Technical Monograph 6

Ayala, G. 2004. *Landscape/Land Use Change In North-central Sicily: A Geoarchaeological Approach*. Unpublished PhD thesis, University of Cambridge

Ayala, G. and French, C. 2005. Erosion modeling of past land use practices in the Fiume di Sotto di Troina valley. *Geoarchaeology* 20(2), 149–67

Bailiff, I. K., French, C. and Scarre, C. 2014. Application of luminescence dating and geomorphological analysis to the study of landscape evolution, settlement and climate change on the Channel island of Herm. *Journal of Archaeological Science* 41, 890–903

Baker, L. L. and Durand, S. R. (eds) 2003. *Prehistory of the Middle Rio Puerco Valley, Sandoval County, New Mexico*. Portales: Archaeological Society of New Mexico Special Publication 3

Balée, W. 1998. Historical ecology: premises and postulates. In Balée, W. (ed.) *Advances in Historical Ecology*, 13–29. New York: Columbia University Press

Banerjea, R. Y., Bell, M., Matthews, W. and Brown, A. 2015. Applications of micromorphology of understanding activity areas and site formation processes in experimental hut floors. *Journal of Archaeological Anthropological Sciences* 7, 89–112

Barber, K. 1988. A critical review of pollen-analytical research in the environmental archaeology of central southern England. *Circea* 5(2), 111–14

Barrett, J. C. 1994. *Fragments from Antiquity: an archaeology of social life in Britain, 2900–1200 BC*. Oxford: Blackwell

Barrett, J., Bradley, R. and Green, M. 1991a. *Landscape, Monuments and Society: the prehistory of Cranborne Chase*. Cambridge: Cambridge University Press

Barrett, J., Bradley, R. and Hall, M. 1991b. *Papers on the Prehistoric Archaeology of Cranborne Chase*. Oxford: Oxbow Monograph 11

Barton, C. M., Ullah, I. and Mitasova, H. 2010. Computational modeling and Neolithic socioecological dynamics: A case study from southwest Asia. *American Antiquity* 75(2), 364–86

Bell, M. G. 1990. *Brean Down Excavations 1983–1987*. London: English Heritage Archaeological Report 15

Bell, M. G. 1992. The prehistory of soil erosion. In Bell and Boardman (eds) 1992, 21–36

Bell, M. G. and Boardman, J. 1992. *Past and Present Soil Erosion: archaeological and geographical perspectives*. Oxford: Oxbow Monograph 22

Bell, M. G., Fowler, P. and Hillson, S. 1996. *The Experimental Earthwork Project, 1960–1992*. York: Council for British Archaeology Research Report 100

*Bell, M. G. and Walker, M. J. C. 2005. *Late Quaternary Environmental Change: physical and human perspectives* (2nd edn). Harlow: Pearson Education /Prentice Hall

Beresford-Jones, D. 2011. *The Lost Woodlands of Ancient Nasca. A Case-study in Ecological and Cultural Collapse*. Oxford: British Academy Postdoctoral Monograph Series.

Beresford-Jones, D. G., Lewis, H. and Boreham, S. 2009a. Linking cultural and environmental change in Peruvian prehistory: geomorphological survey of the Samaca Basin, lower Ica Valley. *Catena* 78, 234–49

Beresford-Jones, D. G., Arce Torres, S., Whaley, O. Q. and Chepstow-Lusty, A. J. 2009b. The role of *Prosopis* in ecological and landscape change in the Samaca Basin, Lower Ica Valley, South Coast Peru from the Early Horizon to the Late Intermediate Period. *Latin American Antiquity* 20, 303–32

Bethell, P. and Mate, I. 1989. The use of phosphate analysis in archaeology: a critique. In Henderson, J. (ed.) *Scientific Analysis in Archaeology*, 1–29. Oxford: Oxford Committee for Archaeology Monograph 19

Bewley, R., Crutchley, S. and Shell, C. A. 2005. New light on an ancient landscape: lidar survey in the Stonehenge World Heritage Site. *Antiquity* 79, 636–47

Boismier, W. A. 1997. *Modelling the Effects of Tillage Processes on Artefact Distributions in the Ploughzone*. Oxford: British Archaeological Report 259

Boivin, N. 2000. Life rhythms and floor sequences: excavating time in rural Rajasthan and Neolithic Catalhoyuk. *World Archaeology* 31, 367–88

Boivin, N. and French, C. 1997–8. New questions and answers in the micromorphology of the occupation deposits at the Souks site, Beirut. *Berytus Archaeological Studies* 43, 181–210

Boreham, S., Milner, N., Taylor, B., Needham, A., Boreham, J. and Rolfe, C. J. 2011. Geochemical indicators of preservation status and site deterioration at Star Carr. *Journal of Archaeological Science* 38, 1–25

Bradley, R. 1978. *The Prehistoric Settlement of Britain*. London: Routledge & Kegan Paul

Bradley, R. 1998. *The Significance of Monuments: on the shaping of human experience in Neolithic and Bronze Age Europe*. London: Routledge

Bradshaw, R. H. W. 1981. Modern pollen representation factors for woods in south-east England. *Journal of Ecology* 69, 45–70

Bridges, E. M. 1978. *World Soils* (2nd edn). Cambridge: Cambridge University Press

Briz, I., Álvarez, M., Balbo, A., Zurro, D., Madella, M., Villagrán, X., French, C., Vila, A. and Estévez, J. 2011. Towards high-resolution shell midden archaeology: experimental and ethno-archaeology in Tierra del Fuego (Argentina). *Quaternary International* 239, 125–34

Brown, A. G. 1997. *Alluvial Geoarchaeology and Environmental Change*. Cambridge: Cambridge University Press

Brown, A. G. 1999. Geomorphological techniques in Mediterranean landscape archaeology. In Leveau, P., Walsh, K., Trement, F. and Barker, G. (eds) *Environmental Reconstruction in Mediterranean Landscape Archaeology*, vol. 2, 45–54. Oxford: Oxbow Books

Bullock, P. and Murphy, C. P. 1979. Evolution of a paleo-argillic brown earth (Paleudalf) from Oxfordshire, England. *Geoderma* 22, 225–52

Bullock, P. and Murphy, C. P. (eds) 1983. *Soil Micromorphology*. Proceedings of the International Working Meeting on Soil Micromorphology, August 1981. Berkhamsted: A. B. Academic

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G. and Tursina, T. 1985. *A Handbook of Soil Thin Section Description*. Wolverhampton: Waine Research

Burrough, P. A. 1986. *Principles of Geographical Information Systems for Land Resources Assessment*. Oxford: Monographs on Soil and Resources Survey 12

Burton, R. G. O. 1981. *Soils in Cambridgeshire II*. Harpenden: Soil Survey Record 69

Butzer, K. W. 1981. Rise and fall of Aksum, Ethiopia: a geo-archaeological interpretation. *American Antiquity* 46(3), 471–95

Butzer, K.W. 1982. *Archaeology as Human Ecology: method and theory for a contextual approach*. Cambridge: Cambridge University Press

Campbell, J. A. M. 2000. *Holocene Palaeoenvironments of Guernsey and Alderney, Channel Islands.* Unpublished PhD thesis, Coventry University

*Campbell, G., Moffett, L. and Straker, V. 2011. *Environmental Archaeology: a guide to the theory and practice, from sampling and recovery to post-excavation* (2nd edn). Swindon: English Heritage

Canti, M. G. 1995. A mixed-method approach to geoarchaeological analysis. In Barham, A. J. and Macphail, R. I. (eds) *Archaeological Sediments and Soils: their analysis, interpretation and management*, 183–90. London: Archtype Books

Canti, M. G. and Linford, N. 2000. The effects of fire on archaeological soils and sediments: Temperature and colour relationships. *Proceedings of the Prehistoric Society* 66, 385–95

Caple, C. 1993. Defining a reburial environment; research problems characterising waterlogged anoxic environments. In Hoffman, P. (ed.) *Proceeedings of the 5th ICOM Group on Wet Organic Archaeological Materials Conference, Portland, Maine*, 407–21. Bremerhaven

Caple, C. and Dungworth, D. 1997. Investigations into waterlogged burial environments. In Sinclair, A., Slater, E. A. and Gowlett, J. (eds) *Archaeological Science 1995*, 233–40. Oxford: Oxbow Books

Caple, C., Dungworth, D. and Clogg, P. 1997. Results of the characterisation of the anoxic waterlogged environments which preserve archaeological organic materials. In Hoffman, P.

(ed.) *Proceedings of the 6th ICOM Group on Wet Organic Archaeological Materials Conference, York, 1996*, 57–72. Bremerhaven

Carré, M., Sachs, J. P., Schauer, A. J., Rodrguez, W. E., and Ramos, F. C. 2013. Reconstructing El Niño-Southern Oscillation activity and ocean temperature seasonality from short-lived marine mollusk shells from Peru. *Palaeogeography, Palaeoclimatology, Palaeoecology* 371, 45–53

Castro, P. V., Chapman, R. W., Gili, S., Lull, V., Mico, R., Rihute, C., Risch, R. and Sanahuja, M. E. (eds). 1998. *Aguas Project: Palaeoclimatic reconstruction and the dynamics of human settlement and land use in the area of the middle Aguas (Almeria), in the south-east of the Iberian Peninsula*. Luxembourg: European Commission Contract No EV-5V-CT94-0487

Catt, J. A. 1978. The contribution of loess to soils in southern England. In Limbrey, S. and Evans, J. G. (eds) *The Effect of Man on the Landscape: the lowland zone*, 12–20. London: Council for British Archaeology Research Report 21

Catt, J. A. 1979. Soils and Quaternary geology in Britain. *Journal of Soil Science* 30, 607–42

Challands, A., Edmonds, M. and Richards, C. 2005. Beyond the village: Barnhouse Odin and the Stones of Stenness. In Richards (ed.) 2005, 205–28

Chapman, H. P. and Cheetham, J. L. 2002. Monitoring and modeling saturation as a proxy indicator for *in situ* preservation in wetlands: a GIS approach. *Journal of Archaeological Science* 29, 277–89

Chapman, H. P. and Kimstach, V. 1992. The selection of water quality monitoring variables. In Chapman, D. (ed.) *Water Quality Assessments. A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring*, 51–119. London: Chapman and Hall

Clark, A. 1996. *Seeing Beneath the Soil: prospecting methods in archaeology* (2nd edn). London: Routledge

Clark, M. and Small, J. 1982. *Slopes and Weathering*. Cambridge: Cambridge University Press

Cleal, R. M. J., Walker, K. E. and Montague, R. 1995. *Stonehenge in its Landscape*. London: English Heritage Archaeological Report 10

Cleal, R. M. J., Allen, M. J. and Newman, C. 2004. An archaeological and environmental study of the Neolithic and later prehistoric landscape of the Avon valley and Durrington Walls environs. *Wiltshire Archaeological and Natural History Magazine* 97, 218–48

Coles, B. 1995. *Wetland Management: a survey for English Heritage*. Exeter: WARP Occasional Paper 9

Cook, A. G. 1999. Asentamientos Paracas en la Valle Bajo de Ica, Peru. *Gaceta Arqueologica Andina* 25, 61–91

Cooke, R., Warren, A. and Goudie, A. 1993. *Desert Geomorphology*. London: University College Press

Conolly, J. and Lake, M. W. 2006. *Geographical Information Systems in Archaeology*. Cambridge: Cambridge Manuals in Archaeology

Courty, M-A., Goldberg, P. and Macphail, R. I. 1989. *Soils and Micromorphology in Archaeology*. Cambridge: Cambridge University Press

Courty, M-A., Goldberg, P. and Macphail, R. I. 1994. Ancient people-lifestyles and cultural patterns. In Wilding, L. and Oleshko, K. (eds) *Micromorphological Indicators of Anthropogenic Effects on Soils*, 250–69. Acapulco: International Conference of Soil Science

Cromarty, A. M., Barclay, A., Lambrick, G. and Robinson, M. 2006. *The Archaeology of the Wallingford Bypass 1986–92*, 194–6. Oxford: Thames Valley Monograph 22

Crowther, J. 1997. Soil phosphate surveys: critical approaches to sampling, analysis and interpretation. *Archaeological Prospection* 4, 93–102

Crowther, J. and Barker, P. 1995. Magnetic susceptibility: distinguishing anthropogenic effects from the natural. *Archaeological Prospection* 2, 207–15

Crowther, J. Macphail. R. I. and Cruise, G. M. 1996. Short-term burial change in a humic rendzina, Overton Down Experimental Earthwork, Wiltshire, England. *Geoarchaeology* 11, 95–117

Crumley, C. L. (ed.) 1994. *Historical Ecology*. Santa Fe: School of American Research Press

Dalrymple, J. B., Blong, R. J. and Conacher, A. J. 1968. A hypothetical nine unit landsurface model. *Zeitschrift fur Geomorphologie* 12, 60–76

Davies, P. 2008. *Snails: archaeology and landscape change*. Oxford: Oxbow Books

Dimbleby, G. W. 1962. *The Development of the British Heathlands and Their Soils*. Oxford: Oxford Forestry Memoir 23

Duller, G. A. T. 2008. *Luminescence Dating: guidelines on using luminescence dating in archaeology*. Swindon: English Heritage

Edwards, K. J. 1993. Models of mid-Holocene forest farming for north-west Europe. In Chambers, F. W. (ed.) *Climate Change and Human Impact*, 133–45. London: Chapman & Hall

Eitel, B. and Mächtle, B. 2009. Man and environment in the Eastern Atacama Desert (Southern Peru): Holocene climate changes and their impact on Pre-Columbian cultures. In Reindel, M. and Wagner, G. A. (eds) *New Technologies for Archaeology: Multidisciplinary Investigations in Palpa and Nasca, Peru*, 17–38. Berlin: Springer

Eitel, B., Hecht, S., Machtle, B., Schkraft, G., Kadereit, A., Wagner, G., Kromer, B., Unkel, I. and Reindel, M. 2005. Geoarchaeological evidence from desert loess in the Nazca-Palpa region, south Peru: palaeoenvironmental changes and their impact on pre-Columbian cultures. *Archaeometry* 47(1), 137–58

Engel, F. 1957. Early sites on the Peruvian coast. *Southwestern Journal of Anthropology* 13(1), 54–68

Engel, F. 1981. *Prehistoric Andean Ecology: man, settlement and environment in the Andes*. New York: Humanities Press

*English Heritage. 2007. *Geoarchaeology: using earth sciences to understand the archaeological record* (2nd edn). Swindon: English Heritage

English Heritage. 2008. *Geophysical Survey in Archaeological Field Evaluation*. Swindon: English Heritage

Entwistle, J. A., Abrahams, P. W. and Dodgshon, R. A. 2000. The geoarchaeological significance and spatial variability of a range of physical and chemical properties from a former habitation site, Isle of Syke. *Journal of Archaeological Science* 27, 287–303

Etayo-Cadavid, M. F., Andrus, C. F. T., Jones, K. B., Hodgins, G. W. L. and Sandweiss, D. H. 2013. Marine radiocarbon reservoir age variation in Donax obesulus shells from northern Peru: Late Holocene evidence for extended El Nino. *Geology (Boulder)* 41, 599–602

Evans, C. 2009. *Fengate Revisited: further fen-edge excavations, Bronze Age field systems and settlement, and the Wyman Abbott/Leeds archives*. Cambridge: Cambridge Archaeological Unit Landscape Archives 1

Evans, C. and Hodder, I. 2006a. *A Woodland Ecology: Neolithic Sites at Haddenham*. Cambridge: McDonald Institute Monograph

Evans, C. and Hodder, I. 2006b. *Marshland Communities and Cultural Landscapes*. Cambridge: McDonald Institute Monograph

Evans, C. and Tabor, J. 2008. *The Over Narrows: archaeological investigations in Hanson's Needingworth Quarry. The Low Grounds*. Cambridge: Cambridge Archaeological Unit Report 940

Evans, J. G. 1972. *Land Snails in Archaeology*. London: Seminar Press

Evans, J. G. 1999. *Land and Archaeology: histories of human environment in the British Isles*. Stroud: Tempus

*Evans, J. G. and O'Connor, T. 2005. *Environmental Archaeology: principles and methods* (2nd edn). Stroud: Sutton Publishing.

Farmer, E. E. 1973. Relative detachability of soil particles by simulated rainfall. *Soil Science Society of America Proceedings* 37, 629–33

Favis-Mortlock, D., Boardman, J. and Bell, M. G. 1997. Modelling long-term anthropogenic erosion of a loess cover, South Downs, UK. *Holocene* 7, 79–90

Fedoroff, N. 1968. Genese et morphologie des sols a horizon b textural en France atlantique, *Science du Sol* 1, 29–65

Flannery, K. V. (ed.) 1976. *The Early Mesoamerican Village*. New York: Academic Press

Fisher, P. F. 1982. A review of lessivage and Neolithic cultivation in southern England. *Journal of Archaeological Science* 9(3), 299–304

FitzPatrick, E. A. 1986. *An Introduction to Soil Science* (2nd edn). Harlow: Longman

Fox, C. 1923. *The Archaeology of the Cambridge Region*. Cambridge: Cambridge University Press
Fox, C. 1938. *The Personality of Britain*. Cardiff: National Museum of Wales and University of Wales
French, C. 1980. An analysis of sediments from two Bronze Age ditches at the Newark Road site, Fengate. In Pryor 1980, 190–202
French, C. 1988a. Aspects of buried prehistoric soils in the lower Welland valley and the fen margin north of Peterborough, Cambridgeshire. In Groenman-van Waateringe, W. and Robinson, M. (eds) *Man-made Soils*, 115–28. Oxford: British Archaeological Report S410
French, C. 1988b. Further aspects of the buried prehistoric soils in the fen margin northeast of Peterborough, Cambridgeshire. In Murphy, P. and French, C. (eds) *The Exploitation of Wetlands*, 193–211. Oxford: British Archaeological Report 186
French, C. 1990. Neolithic soils, middens and alluvium in the lower Welland valley. *Oxford Journal of Archaeology* 9(3), 305–11
French, C. 1994. *Excavation of the Deeping St Nicholas Barrow Complex, South Lincolnshire.* Sleaford: Lincolnshire Archaeology and Heritage Report 1, Fenland Management Project
French, C. 1998. Soils and sediments. In Pryor 1998, 311–31
French, C. 2001. The development of the Flag Fen and Fengate prehistoric landscape. In Pryor 2001, 20–2, 39–43, 53–8, 382–3, 400–4, 437–47, 450
*French, C. 2003. *Geoarchaeology in Action: studies in soil micromorphology and landscape evolution.* London: Routledge
French, C. 2005. Analysis of the soil deposits at Barnhouse and Maes Howe. In Richards (ed.) 2005, 371–80
French, C. 2009a. Hydrological monitoring of an alluviated landscape in the lower Great Ouse valley at Over, Cambridgeshire: the quarry restoration phase. *Environmental Archaeology* 14(1), 63–76
French, C. (ed.) 2009b. *Developing International Geoarchaeology*. *Catena* 78 (Special Issue), 3
French, C. 2010a. The palaeo-environments of Bronze Age Europe. In Earle, T. and Kristiansen, K. (eds) *Organizing Bronze Age Societies: the Mediterranean, Central Europe and Scandinavia compared*, 34–56. Cambridge: Cambridge University Press
French, C. 2010b. People, society and landscapes. *Science* 328, 443–44
French, C. 2010c. Sustaining prehistoric agricultural landscapes in southern Spain, highland Yemen and northern New Mexico: the geoarchaeological perspective. In Lewis, H. and Semple, S. (eds) *Perspectives in Landscape Archaeology*, 37–44. Oxford: British Archaeological Report S2103
French, C. forthcoming a. The micromorphological analyses of the palaeosols and floor deposits at Durrington Walls. In Parker-Pearson *et al*. forthcoming
French, C. forthcoming b. Crossiecrown, Mainland, Orkney: the micromorphological analysis of the midden and floor deposits associated with the excavated structures. In Richards, C. and Jones, R. E. (eds) *A Prehistory of Neolithic Chambered Cairn Building Communities in West Mainland, Orkney: Investigations at Skaill Bay, Stonehall, Wideford Hill and Crossiecrown*
French, C. and Kousoulakou, M. 2003. Geomorphological and micromorphological investigations of palaeosols, valley sediments and a sunken floored dwelling at Botai, Kazakhstan. In Levine, M., Renfrew, C. and Boyle, K. (eds) *Prehistoric Steppe Adaptation and the Horse*, 105–14. Cambridge: McDonald Institute Monograph
French, C. and Lewis, H., with contributions by Scaife, R. and Allen, M. 2005. Archaeological and palaeoenvironmental investigations of the upper Allen valley, Cranborne Chase, Dorset. *Geoarchaeology*, 20(2), 109–34
French, C. and Pryor, F. 1993. *The South-west Fen Dyke Survey, 1982–86*. Cambridge: East Anglian Archaeology 59
French, C. and Pryor, F. 2005. *Archaeology and Environment of the Etton Landscape*. Peterborough: East Anglian Archaeology 109
French, C. and Taylor, M. 1985. Desiccation and destruction: the immediate effects of de-watering at Etton, Cambridgeshire. *Oxford Journal of Archaeology* 4(2), 139–55

French, C., Macklin, M. and Passmore, D. 1992. Archaeology and palaeochannels in the lower Welland and Nene valleys: alluvial archaeology at the fen-edge, eastern England. In Needham, S. and Macklin, M. (eds) *Archaeology under Alluvium*, 169–76. Oxford: Oxbow Monograph 27

French, C., Passmore, D. and Schulte, L. 1998. Geomorphology and edaphic factors. In Castro *et al.* (eds) 1998, 45–52

French, C., Sulas, F. and Madella, M. 2009. New geoarchaeological investigations of the valley systems in the Aksum area of northern Ethiopia. *Catena* 78(3), 218–33

French, C., Sulas, F. and Petrie. C. A. 2014. Expanding the research parameters of geoarchaeology: case studies from Aksum in Ethiopia and Haryana in India. *Archaeological and Anthropological Sciences* on-line 16/03/2014

French, C., Lewis, H., Allen, M. J. and Scaife, R. G. 2000. Palaeoenvironmental and archaeological investigations on Wyke Down and in the upper Allen valley, Cranborne Chase, Dorset, England: interim summary report for 1998–9. *Proceedings of the Dorset Natural History and Archaeological Society* 122, 53–71

French, C., Lewis, H., Allen, M. J. and Scaife, R. 2003. Archaeological and palaeoenvironmental investigations of the upper Allen valley, Cranborne Chase, Dorset (1998–2000): a new model of earlier Holocene landscape development. *Proceedings of the Prehistoric Society* 69, 210–34

French, C., Lewis, H., Allen, M. J., Green, M., Scaife, R. and Gardiner, J. 2007. *Prehistoric Landscape Development and Human Impact in the Upper Allen Valley, Cranborne Chase, Dorset*. Cambridge: McDonald Institute Monograph

French, C., Periman, R., Scott Cummings, L., Hall, S., Goodman-Elgar, M. and Boreham, J. 2009. Holocene alluvial sequences, cumulic soils and fire signatures in the middle Rio Puerco basin at Guadalupe Ruin, New Mexico. *Geoarchaeology* 24(5), 638–76

French, C., Scaife, R. and Allen, M. J., with Parker Pearson, M., Pollard, J., Richards, C., Thomas, J. and Welham, K. 2012. Durrington Walls to West Amesbury by way of Stonehenge: a major transformation of the Holocene landscape. *Antiquaries Journal* 92, 1–36

Friesem, D., Boaretto, E., Eliyahu-Behar, A. and Shahack-Gross, R. 2011. Degradation of mud brick houses in an arid environment: a geoarchaeological model. *Journal of Archaeological Science* 38, 1–13

Gdaniec, K., Edmonds, M. and Wiltshire, P. 2007. *A Line Across Land: fieldwork on the Isleham-Ely pipeline, 1993–4*. Cambridge: East Anglian Archaeology 121

Gebhardt, A. 1992. Micromorphological analysis of soil structural modificaton caused by different cultivation implements. In Anderson, P. C. (ed.) *Prehistoire de l'Agriculture: nouvelles approaches experimentales et ethnographiques*, 373–92. Paris: Centre Nationale de la Recherche Scientifique, Monographie de C.R.A. 6

Gebhardt, A. 1995. Soil micromorphological data from traditional and experimental agriculture. In Barham, A. J. and Macphail, R. I. (eds) *Archaeological Sediments and Soils: analysis, interpretation and management*, 25–40. London: Institute of Archaeology

Gerrard, J. 1992. *Soil Geomorphology: an integration of pedology and geomorphology*. London: Chapman and Hall

Glazebrook, J. (ed.) 1997. *Research and Archaeology: a framework for the eastern Counties, 1. Resource assessment*. Norwich: East Anglian Archaeology Occasional Paper 3

*Goldberg, P. and Macphail, R. I. 2006. *Practical and Theoretical Geoarchaeology*. Oxford: Blackwell Publishing

Goodman-Elgar, M. 2008. The devolution of mudbrick: ethnoarchaeology of abandoned earthen dwellings in the Bolivian Andes. *Journal of Archaeological Science* 35, 3057–71

Goudie. A. (ed.) 1990. *Geomorphological Techniques* (2nd edn). London: Unwin Hyman

Green, M. and Allen, M. J. 1997. An early prehistoric shaft on Cranborne Chase. *Oxford Journal of Archaeology* 16(2), 1–32

Grun, R. 2001. Trapped charge dating (ESR, TL, OSL). In Brothwell, D. R. and Pollard, A. M. (eds) *Handbook of Archaeological Sciences*, 47–62. Chichester: John Wiley & Sons

Guttman, E. B. A., Dockrill, S. J. and Simpson, I. A. 2004. Arable agriculture in prehistory: new evidence from soils in the Northern Isles. *Proceedings of the Society of Antiquaries of Scotland* 134, 53–64

Hall, D. and Coles, J. 1994. *Fenland Survey: an essay in landscape and persistence*. London: English Heritage Archaeological Report 1

Hamlet, L. E. 2014. *Anthropic Sediments on the Scottish North Atlantic Seaboard: nature, versatility and value of a midden*. Unpublished PhD thesis, University of Stirling

Haselgrove, C., Millett, M. and Smith, I. (eds) 1985. *Archaeology from the Ploughsoil: studies in the collection and interpretation of field survey data*. Sheffield: University of Sheffield

Hazeldon, J. 2003. *The Soils of Alderney*. Unpublished report, University of Reading

Hearne, C. and Birbeck, V. 1999. *A35 Topuddle to Puddleton Bypass DBFO, Dorset, 1996–8*. Salisbury: Wessex Archaeology Report 15

Hepworth, N. D., Postigo, J. C., Guemes Delgada, B. and Kjell, P. 2010. *Drop by Drop: Understanding the impacts of the UK's water footprint through a case study of Peruvian asparagus*. London: Progressio/Lima: Peruvian Centre for Social Studies/Edinburgh: Water Witness International

Hesse, P. R. 1971. *A Textbook of Soil Chemical Analysis*. London: John Murray

Hinchliffe, J. and Schadla-Hall, R. T. (eds) 1980. *The Past Under the Plough*. London: Directorate of Ancient Monuments and Historic Buildings Occasional Paper 3

Holden, J., Jared West, L., Howard, A. J., Maxfield, E., Panter, I. and Oxley, J. 2006. Hydrological controls of *in situ* preservation of waterlogged archaeological deposits. *Earth-Science Reviews* 78, 59–83

Holliday, V. T. 2004. *Soils in Archaeological Research*. Oxford: Oxford University Press

Holliday, V. T. and Gartner, W. 2007. Methods of P analysis in archaeology. *Journal of Archaeological Science* 34, 301–33

Horton, R. E. 1945. Erosional development of streams and their drainage basins: a hydrophysical approach to quantitative morphology. *Bulletin of the Geological Society of America* 56, 275–370

Hoskins, W. G. 1955. *The Making of the English Landscape*. London: Hodder and Stoughton

Howard, A. J. and Macklin, M. G. 1999. A generic geomorphological approach to archaeological interpretation and prospection in British river valleys: a guide for archaeologists investigating Holocene landscapes. *Antiquity* 73, 527–41

Hutton, J. 1788. Theory of the earth, or the investigation of the laws observable in the composition, dissolution and restoration of land upon the globe. *Transactions of the Royal Society of Edinburgh* 1, 209–304

Imeson, A. C., Kwaad, F. J. P. M. and Mucher, H. J. 1980. Hillsope processes and deposits in the forested areas of Luxembourg. In Cullingford, R. A., Davidson, D. A. and Lewin, J. (eds) *Timescales in Geomorphology*, 31–42. New York: Wiley

Jones, R., Challands, A., French, C., Card, N., Downes, J. and Richards, C. 2010. Exploring the location and function of a Late Neolithic house at Crossiecrown, Orkney by geophysical, geochemical and soil micromorphological methods. *Archaeological Prospection* 17, 29–47

Jongerius, A. 1970. Some morphological aspects of regrouping phenomena in Dutch soils. *Geoderma* 4, 311–31

Jongerius, A. 1983. The role of micromorphology in agricultural research. In Bullock and Murphy (eds) 1983, 111–38

Kerney, M. P. and Cameron. R. A. D. 1979. *A Field Guide to the Land Snails of Britain and North-west Europe*. London: Collins

Keeley, H. C. M. and Macphail, R. I. 1981. *A Soil Handbook for Archaeologists. Institute of Archaeology Bulletin* 18, 225–41

Killick, R. and Moon, J. (eds) 2005. *The Early Dilmun Settlement at Saar*. Ludlow: London-Bahrain Archaeological Expedition, Saar Excavation Report 3

Kirkby, M. J. 1969a. Erosion by water of hillslopes. In Chorley, R. J. (ed.) *Water, Earth and Man*, 229–38. London: Methuen

Kirkby, M. J. 1969b. Infiltration, throughflow and overland flow. In Chorley, R. J. (ed.) *Water, Earth and Man*, 215–27. London: Methuen

Kirkby, M. J., Baird, A. J., Diamond, S. M., Lockwood, J. G., McMahon, M. L. Mitchell, P. L., Shao, J., Sheehy, J. E., Thornes, J. B. and Woodward, F. I. 1996. The MEDALUS slope catena model: a physically based process model for hydrology, ecology and land degradation interactions. In Brandt, C. J. and Thornes, J. B. (eds) *Mediterranean Desertification and Land Use*, 303–54. Chichester: Wiley

Kooistra, M. J. and Pulleman, M. M. 2010. Features related to faunal activity. In Stoops *et al.* (eds) 2010, 397–418

Kuhn, P., Aguilar, J. and Miedema, R. 2010. Textural pedofeatures and related horizons. In Stoops *et al.* (eds) 2010, 217–50

Kvamme, K. L. 1993. Spatial statistics and GIS: an integrated approach. In Andersen, J., Madsen, T. and Scollar, I. (eds) *Computing the Past: Computing Applications and Quantitative Methods in Archaeology*, 91–104. Aarhus: Aarhus University Press

Kwaad, F. J. P. M. and Mucher, H. J. 1979. The formation and evolution of colluvium on arable land in Northern Luxembourg. *Geoderma* 22, 173–92

Kwan, M. P. and Lee, J. 2004. Geovisualization of human activity patterns using 3D GIS: a time-geographic approach. In Goodchild, M. F. and Janelle, D. G. (eds) *Spatially Integrated Social Science*, 48–66. Oxford: Oxford University Press

Lane, K. 2006. Through the looking glass: re-assessing the role of agro-pastoralism in the north-central Andean highlands. *World Archaeology* 38(3), 493–510

Lane, K. 2009. Engineered highlands: The social organisation of water in the ancient north-central Andes (AD 1000–1480). *World Archaeology* 41(1), 169–90

Lang, A. and Wagner, G. A. 1996. Infrared stimulated luminescence dating of archaeosediments. *Archaeometry* 38, 129–41

Langbein, W. B. and Schaum, S. A. 1958. Yield of sediment in relation to mean annual precipitation. *Transactions of the American Geophysical Unit* 39, 1076–84

Lewis, H. 1998. *The Characterisation and Interpretation of Ancient Tillage Practices Through Soil Micromorphology: a Methodological Study*. Unpublished PhD thesis, University of Cambridge

Lewis, H. 2002. An investigation of ancient cultivation at Hengistbury Head Site 6, Christchurch, Dorset. *Proceedings of the Prehistoric Society* 68, 83–102

Lewis, H. 2012. *Investigating Ancient Tillage: An experimental and soil micromorphological study*. Oxford: British Archaeological Report S2388

Lillie, M. 2007. *In situ* preservation: Geo-archaeological perspectives on an archaeological nirvana. In Lillie and Ellis (eds) 2007, 156–72

Lillie, M. and Cheetham, J. 2002. *Water Table Monitoring at Flag Fen, Peterborough*. Unpublished report SAS-FF/02-01, University of Hull: Wetland Archaeology and Environments Research Centre

Lillie, M. and Ellis, S. 2007. Wetland archaeology and environments. In Lillie, M. and Ellis, S. (eds) *Wetland Archaeology and Environments: regional issues, global perspectives*, 3–10. Oxford: Oxbow Books

Limbrey, S. 1975. *Soil Science in Archaeology*. London: Academic Press

Lock, G. and Stancic, Z. (eds) 1995. *Archaeology and Geographical Information Systems: a European perspective*. London: Taylor and Francis

Londono, A. C., Forman, S. L., Eichler, T. and Pierson, J. 2012. Episodic eolian deposition in the past ca. 50,000 years in the Alto Ilo dune field, southern Peru. *Palaeogeography, Palaeoclimatology, Palaeoecology* 346–7, 12–24

Love, D. W., Hawley, J. W. and Young, J. D. 1982. Preliminary report on the geomorphic history of the lower Rio Puerco in relation to archaeological sites and cultural resources of the lower Hidden Mountain Dam site. In Eidenbach, P. L. (ed.) *Inventory Survey of the Lower Hidden Mountain Floodpool, Lower Rio Puerco Drainage, Central New Mexico*, 21–65. Tularosa: Human Systems Research

Mackereth, F. J. H. 1965. Chemical investigations of lake sediments and their interpretation. *Proceedings of the Royal Society of London* 161B, 295–309

Macphail, R. I. 2000. Soils and micromorphology: a soil micromorphological and micro-chemical approach. In Lawson, A (ed.) *Potterne 1982–5: animal husbandry in later prehistoric Wessex*, 47–71. Salisbury: Wessex Archaeology Report 21

Macphail, R. I. and Cruise, G. M. 1996. Soil micromorphology. In Bell *et al.* (eds) 1996, 95–107

Macphail, R. I. and Goldberg, P. 2000. Geoarchaeological investigations of sediments from Gorham's and Vanguard Caves, Gibralter: microstratigraphical (soil micromorphological and chemical) signatures. In Stringer, C. B., Barton, R. N. E. and Finlayson, C. (eds) *Neanderthals on the Edge*, 183–200. Oxford: Oxbow Books

Macphail, R. I., Romans, J. C. C. and Robertson, L. 1987. The application of soil micromorphology to the understanding of Holocene soil development in the British Isles, with special reference to early cultivation. In Fedoroff, N., Bresson, L. M. and Courty, M-A. (eds) *Soil Micromorphology*, 647–56. Plaisir: Association Francaise pour l'Etude du Sol

Macphail, R. I., Courty, M-A. and Gebhardt, A. 1990. Soil micromorphological evidence of early agriculture in north–west Europe. *World Archaeology* 22, 53–69

Malone, C. and Stoddart, S. 2000. A house in the Sicilian hills. *Antiquity* 74, 471–2

Massey, S. A. 1991. Social and political leadership in the lower Ica valley: Ocucaje Phase 8 and 9. In Paul, A. (ed.) *Paracas Art and Architecture*, 349–416. Iowa City: University of Iowa Press

Matthews, W. 2003. Microstratigraphic sequences: indications of uses and concepts of space. In Matthews, R. (ed.) *Excavations at Tell Brak, Vol. 4: Exploring an Upper Mesoptamian regional centre, 1994–1996*, 377–388. London: British School of Archaeology in Iraq/Cambridge: McDonald Institute

Matthews, W. 2005. Micromorphological and microstratigraphic traces of uses and concepts of space. In Hodder, I. (ed.) *Inhabiting Catalhoyuk. Reports of the 1995–99 seasons*, 355–98, 553–72. Cambridge: McDonald Institute/British Institute of Archaeology at Ankara

Matthews, W. 2010. Geoarchaeology and taphonomy of plant remains and micrmorphological residues in early urban environments in the ancient Near East. *Quaternary International* 214, 98–113

Matthews, W. and French, C. 2005. Domestic space at Saar: the microstratigraphic evidence. In Killick and Moon (eds) 2005, 325–38

Matthews, W., French, C., Lawrence, T. and Cutler, D. F . 1996. Multiple surfaces: the micromorphology. In Hodder, I. (ed.) *On the Surface: Catalhoyuk 1993–95*, 301–42. British Institute of Archaeology at Ankara Monograph 22/Cambridge: McDonald Institute

Matthews, W., French, C., Lawrence, T., Cutler, D. F. and Jones, M. K. 1997a. Microstratigraphic traces of site formation processes and human activities. *World Archaeology* 29(2), 281–308

Matthews, W., French, C., Lawrence, T., Cutler, D. F. and Jones, M. K. 1997b. Activities inside the temple: the evidence of microstratigraphy. In Crawford, H., Killick, R. and Moon, J. (eds) *The Dilmun Temple at Saar*, 31–46. London: Kegan Paul International

Matthews, W., French, C., Lawrence, T., Cutler, D. F. and Jones, M. K. 1998. Microstratigraphy and micromorphology of depositional sequences. In Oates, D., Oates, J. and McDonald, H. *Excavations at Tell Brak, Vol. 1: The Mitanni and Old Babylonian periods*, 135–54. Ankara: British School of Archaeology in Iraq/Cambridge: McDonald Institute

McCulloch, R. D., Bentley, M. J., Tipping, R. M. and Clapperton, C. M. 2005. Evidence for Lateglacial ice dammed lakes in the central Strait of Magellan and Bahía Inútil, southernmost South America. *Geografiska Annaler* 87 A(2), 335–62

McKenzie, J. 2007. *Deep Anthropogenic Topsoils in Scotland: a geoarchaeological and historical investigation into distribution, character and conservation under modern land cove*r. Unpublished PhD thesis, University of Stirling

Medleycott. M. (ed.) 2011. *Research and Archaeology Revisited: a revised framework for the east of England*. Dereham: East Anglian Archaeology Occasional Paper 24

Mighall, T. M., Abraham, P. N., Grattan, J. P., Hayes, D., Timberlake, S. and Forsyth, S. 2002. Geochemical evidence for atmospheric pollution derived from prehistoric copper mining at Copa Hill, Cwmystwyth, mid-Wales, UK. *Science of the Total Environment* 292, 69–80

Milek, K. and French, C. 2007. Soils and sediments in the settlement and harbour at Kaupang. In Skre (ed.) 2007, 321–60

Milner, N., Conneller, C., Elliott, B., Koon, H., Panter, I., Penkman, K., Taylor, B. and Taylor, M. 2011. From riches to rags: organic deterioration at Star Carr. *Journal of Archaeological Science* 38, 2818–32

Moore, P. D. and Webb, J. A. 1978. *An Illustrated Guide to Pollen Analysis*. London: Hodder and Stoughton

Moore, P. D., Webb, J. A. and Collinson, M. E. 1991. *Pollen Analysis* (2nd edn). Oxford: Blackwell Scientific

Morello, F., Torres, J., Martinez, I., Rodriguez, K., Arroyo-Kalin, M., French, C., Sierpe, V. and San Roman, M. 2012. Punta Santa Ana Archaeology: Reconstruction of marine hunter-gatherer occupation sequences from the Magellan Strait, Southernmost Patagonia, Chile. *Magallania* 40(2), 129–49

Morgan, R. P. C. 1979. *Soil Erosion*. London: Longman

Morrison, S. J. L. and Simpson, I. A. 2008. *Jethou, Channel Islands: thin section micromorphology of midden A (JET07)*. Unpublished manuscript, University of Stirling

Murphy, C. P. 1986. *Thin Section Preparation of Soils and Sediments*. Berkhamsted: A.B. Academic

Murray, A. S. and Wintle, A. G. 2000. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* 32, 57–73

Murray, A. S. and Wintle, A. G. 2003. The single aliquot regenerative dose protocol: potential for improvements in reliability. *Radiation Measurements* 37, 377–81

Nials, F. L. 2003. Geology and geomorphology of the middle Rio Puerco valley. In Baker and Durand (eds) 2003, 21–34

Nials, F. L. and Durand, S. R. 2003. Environmental change in the middle Rio Puerco valley. In Baker and Durand (eds) 2003, 35–53

Olivier, A. 1996. *Frameworks for Our Past*. London: English Heritage

Oonk, S., Slomp, C. P. and Huisman, D. J. 2009. Geochemistry as an aid to archaeological prospection and site interpretation: Current issues and research directions. *Archaeological Prospection* 16, 35–51

Ore, M-T., Bayer, D., Chiong, J. and Rendon, E. 2014. Water emergency in oasis of the Peruvian coast: The effects of the agro-export boom in the Ica valley. Hal.archives-ouvertes.fr/hal-010224460

Palmer, R. 1996. Integration of air photo interpretation and field survey projects. *Archaeological Prospection* 2, 167–76

Parker Pearson, M. 2012. *Stonehenge: exploring the greatest Stone Age mystery*. London: Simon & Shuster

Parker Pearson, M., Richards, C., Allen, M., Payne, A. and Welham, K. 2004. The Stonehenge Riverside Project: research design and initial results. *Journal of Nordic Archaeological Science* 14, 45–60

Parker-Pearson, M., Richards, C., Pollard, J., Thomas, J., and Welham, K. forthcoming. *Stonehenge for the Ancestors: The Stonehenge Riverside Project Volume 1*. London: Prehistoric Society Research Paper

Periman, R. 2005. Modeling landscapes and past vegetation patterns of New Mexico's Rio Del Oso Valley. *Geoarchaeology* 20, 193–210

Plog, S. 1976. Relative efficiencies of sampling techniques for archeological surveys. In Flannery (ed.) 1976, 131–59

Popper, K. R. 1972. *Objective Knowledge*. Oxford: Oxford University Press

Preece, R. C. and Bridgeland, D. 1999. Holywell Combe, Folkestone: a 13,000 year history of an English chalkland valley. *Quaternary Science Reviews* 18, 1075–125

Pryor, F. M. M. 1978. *Fengate, Peterborough, England: the Second Report*. Toronto: Royal Ontario Archaeology Monograph 5

Pryor, F. M. M. 1980. *Fengate, Peterborough, England: the Third Report*. Toronto/Northampton: Royal Ontario Archaeology Monograph 6/Northamptonshire Archaeology Monograph 1

Pryor. F. M. M. 1984. *Fengate, Peterborough, England: the Fourth Report*. Toronto/Northampton: Royal Ontario Archaeology Monograph 7/Northamptonshire Archaeology Monograph 2

Pryor, F. 1992. Flag Fen. *Antiquity* 66, 439–547

Pryor, F. 1998. *Excavation of a Neolithic Causewayed Enclosure at Etton, near Maxey, Cambridgeshire, 1982–7*. London: English Heritage Archaeological Report 18

Pryor, F. 2001. *The Flag Fen Basin: archaeology and environment of a Fenland landscape*. London: English Heritage Archaeological Report

Pryor, F. 2010. *The Making of the English Landscape*. London: Penguin

Pryor, F. and French, C. 1985. *Archaeology and Environment in the Lower Welland valley*. Cambridge: East Anglian Archaeology 27

Rapp, G. and Hill, C. 1998. *Geoarchaeology: the earth science approach to archaeological interpretation*. London: Yale University Press

Redman, C. and van der Leeuw, S. 2002. Placing archaeology at the centre of socio-natural studies. *American Antiquity* 67(4), 597–605

Rees-Jones, J. and Tite, M. S. 1997. Optical dating results for British archaeological sediments. *Archaeometry* 39(1), 177–87

Reynolds, P. 1979. *Iron-Age Farm: the Butser Experiment*. London: British Museum Publications.

Richards, C. (ed.) 2005. *Dwelling Among the Monuments: excavations at Barnhouse and Maeshowe*. Cambridge: McDonald Institute Monograph

Richards, J. 1990. *Stonehenge Environs*. London: English Heritage Archaeological Report

Samarasundera, E. 2007. Towards a dynamic ecosystem model for the Neolithic of the upper Allen valley. In French *et al*. 2007, 197–206

Sandweiss, D. H. and Kelley, A. R. 2012. Archaeological contributions to climate change research: the archaeological record as a paleoclimatic and paleoenvironmental archive. *Annual Review of Anthropology* 41, 371–91

Scaife, R. G. 2001. The vegetation and environment. In Pryor 2001, 351–81

Scaife, R. G. 2004. Sampling and pollen analysis and vegetation history. In Cleal *et al*. 2004, 229–34

Scaife, R. G. 2007. Palynological analyses. In French *et al.* 2007, 43–64

Scarre, C. and French, C. 2013. The palaeogeography and Neolithic archaeology of Herm in the Channel Islands. *Journal of Field Archaeology* 38(1), 1–18

Schiffer, M. B. 1987. *Formation Processes of the Archaeological Record*. Albuquerque: University of New Mexico Press

Scott Cummings, L. 2004. *Pollen and charcoal analysis of stratigraphic samples from Tapia Arroyo and Rio Puerco, New Mexico*. Sante Fe: Paleo Research Institute Technical Report 02–08

Selby, M. J. 1993. *Hillslope Materials and Processes* (2nd edn). Oxford: Oxford University Press

Shahack-Gross, R. 2011. Herbivorous livestock dung: formation, taphonomy, methods for identification, and archaeological significance. *Journal of Archaeological Science* 38, 205–18

Shahack-Gross, R, Gafri, M and Finkelstein, I. 2009. Identifying threshing floors in the archaeological record: A test case at Iron Age Tell Megiddo, Israel. *Journal of Field Archaeology* 34(2), 171–84

Sharples, N. 1991. *Maiden Castle: excavations and field survey 1985–6.* London: English Heritage Archaeological Report 19

Shepherd, R. G. 1978. Distinction of aggradational and degradational fluvial regimes in valley-fill alluvium, Tapia Canyon, New Mexico. In Miall, A. D. (ed.) *Fluvial Sedimentology*, 277–86. Canadian Society of Petroleum Geologists Memoir 5

Shimada, I., Schaaf, C., Thompson, L. and Mosely-Thompson, E. 1991. Cultural impacts of severe droughts in the prehistoric Andes: application of a 1,500-year ice core precipitation record. *World Archaeology* 22(3), 247–65

Simpson, I. A. 1997. Relict properties of anthropogenic deep top soils as indicators of infield land management in Marwick, West Mainland, Orkney. *Journal of Archaeological Science* 24, 365–80

Simpson, I. A. 1998. Early land management at Tofts Ness, Sanday, Orkney: the evidence of thin section micromorphology. In Mills, C. M. and Coles, G. (eds) *Life on the Edge. Human Settlement and Marginality*, 91–8. Oxford: Oxbow Monograph 100

Simpson, I. A., Guttman, E. B., Cluett, J. and Shepherd, A. 2006. Characterising anthropic sediments in north European Neolithic settlements: an assessment from Skara Brae, Orkney. *Geoarchaeology* 21, 221–35

Simpson, I. A., van Bergen, P. F, Perrett, V., Elhammali, M. M., Roberts, D. J. and Evershed, R. P. 1999a. Lipid biomarkers of manuring practice in relict anthropogenic soils. *Holocene* 9, 223–9

Simpson, I. A., Bol, R., Bull, I. D., Evershed, P., Petzke, K. and Dockrill, S. J. 1999b. Interpreting early land management through compound specific stable isotope analyses of archaeological soils. *Rapid Communications in Mass Spectrometry* 13(13), 1315–9

Simpson, W. G., Gurney, D. A., Neve, J. Pryor, F., French, C., Harman, M. and May, J. 1993. *The Fenland Project Number 7, Excavations in Peterborough and the Lower Welland Valley 1960–1969*. Peterborough: East Anglian Archaeology 61

Skre, D. (ed.) 2007. *Kaupang in Skiringssal*. Aarhus University Press and the Kaupang Excavation Project Publication Series 1. Norske Oldfunn XXII, University of Oslo

Slegers, M. F. W. and Stroonsnijder, L. 2008. Beyond the desertification narrative: a framework for agricultural drought in semi-arid East Africa. *Ambio* 37, 372–80

Soil Survey Staff. 1999. *Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys* (2nd edn). Washington DC: USDA, Natural Resources Conservation Service, Agriculture Handbook 436

Speed, C. 2014. *Experimental Archaeology and the Formation Processes of the Archaeological Record: the effects of trampling and soil fauna on geochemical evidence of metalworking*. Unpublished PhD thesis, University of Reading

Stoops, G. 2003. *Guidelines for Analysis and Description of Soil and Regolith Thin Sections.* Madison: Soil Science Society of America

Stoops, G., Marcelino, V. and Mees, F. (eds) 2010. *Interpretation of Micromorphological Features of Soils and Regoliths*. Amsterdam: Elsevier

Statham, I. 1979. *Earth Surface Sediment Transpor*t. Oxford: Clarendon

Statham, I. 1990. Slope processes. In Goudie 1990, 225–59

Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, G., van der Plicht, J. and Spurk, M. 1998. INTCAL98 Radiocarbon Age Calibration 24,000–0 cal BP. *Radiocarbon* 40(3), 1041–83

Stump, D. 2010. 'Ancient and backward' or 'long-lived and sustainable': the role of the past in debates concerning rural livelihoods and resource conservation in eastern Africa. *World Development* 38 (http://www.sciencedirect.com/science)

Sulas, F., Madella, M. and French, C. 2009. State formation and water resources management in the Horn of Africa: the Aksumite Kingdom of northern Ethiopian highlands. *World Archaeology* 41(1), 2–15

Thomas, K. D. 1985. Land snail analysis in archaeology: theory and practice. In Fieller, N. R. J., Gilbertson, D. D. and Ralph, G. A. (eds) *Palaeobiological Investigations: research design, methods and data analysis*, 131–56. Oxford: British Archaeological Report S266

Thornes, J. B. 2005. Coupling erosion, vegetation and grazing. *Land Degradation and Development* 16, 127–38

Thornes, J. B. 2007. Modelling soil erosion by grazing: recent developments and new approaches. *Geographical Research* 45(1), 13–26

Van Andel, T., Zangger, E. and Demitrack, A. 1990. Land use and soil erosion in prehistoric Greece. *Journal of Field Archaeology* 17, 379–96

Van der Noort, R., Chapman, H. and Cheetham, J. 2001. *In situ* preservation as a dynamic process: the example of Sutton Common, UK. *Antiquity* 75, 94–100

Wainwright, G. J. and Longworth, I. H. 1971. *Durrington Walls: Excavations 1966–68*. London: Reports of the Research Committee of the Society of Antiquaries of London 29

Ward, R. C. and Robinson, M. 1990. *Principles in Hydrology* (3rd edn). London: McGraw Hill

*Waters, M. P. 1992. *Principles of Geoarchaeology: a North American perspective.* Tuscon: University of Arizona Press

Watson, E. 2009. *Living Terraces in Ethiopia: Konso landscape, culture and development*. New York: James Currey

Willis, K. J., Braun, M., Sumegi, P. and Toth, A. 1997. Does soil development cause vegetational change or vice versa? A temporal perspective from Hungary. *Ecology* 73, 730–40

Willis, K. J., Braun, M., Sumegi, P. and Toth, A. 1997. Prehistoric land degradation in Hungary: who, how and why? *Antiquity* 72, 101–13

Wilkinson, T. J. 2005. Soil erosion and valley fills in the Yemen Highlands and southern Turkey: Integrating settlement, geoarchaeology and climate change. *Geoarchaeology* 20, 169–92

Wilson, C. A., Davidson, D. A. and Cresser, M. S. 2005. An evaluation of multi-element analysis of historic soil contamination to differentiate space use and former function in and around abandoned farms. *Holocene* 15, 1094–9

Wilson, C. A., Cresser, M. S. and Davidson, D. A. 2008. Multi-element soil analysis: an assessment of its potential as an aid to archaeological interpretation. *Journal of Archaeological Science* 35, 412–24

Wilson, D. R. 2000. *Air Photo Interpretation for Archaeologists* (2nd edn). London: Batsford

Wintle, A. G. and Murray, A. S. 2006. A review of quartz optically stimulated luminescence characteristics and their relevance in single-aliquot regeneration dating protocols. *Radiation Measurements* 41, 369–91

Wischmeier, W. H. and Smith, D. D. 1978. *Predicting Rainfall Losses – a Guide for Conservation.* Washington, DC: Agricultural Research Service Handbook 537

Wolman, M. G. 1967. A cycle of sedimentation and erosion in urban river channels. *Geografiska Annales* 49A, 385–95

Glossary of terms

A horizon: upper organic horizon of a soil; Ah = turf or humic horizon; Ap = ploughsoil: see humus below
Acidic: pH of <6
Aeolian: windblown; associated with loess deposition
Aerobic: oxygenated environment; with iron oxidised to the ferric form (Fe 3+)
Agric horizon: sub-surface horizons formed by the illuviation of mechanically dispersed fine material (i.e. silt, clay and fine humic matter) that have been under cultivation for a long time (Soil Survey Staff 1999)
Agricutan: illuvial coating, generally composed of dusty clay with included very fine organic matter occurring on the surface of the capillary voids which originate from the disturbance of agricultural topsoils and associated rainsplash; the term was 'coined' by Jongerius (1970)
Alluvium: well sorted, homogeneous, freshwater-borne sediment, generally composed of silt and clay size material, entrained in and aggrading in a river valley floodplain situation
Anaerobic (or anoxic): air excluded; with iron reduced to the ferrous, more soluble form (Fe 2+)
Analogue: possible equivalent, similar situation or thing; i.e. ethnographic or experimental analogy
Anastomosing channel: ladder-like river channel system, generally found in a cold, periglacial type of climate
Ard: single share wooden plough of Neolithic, Bronze and Iron Age periods
Argillic brown earth (or sol lessivé): well structured, clay-enriched soil normally developed under woodland on well drained, slightly acidic to calcareous subsoils/substrates in the earlier Holocene
Argillic horizon: clay-enriched lower B (or Bt) horizon of a soil (as above)
Avulsion: lateral movement and re-routing of stream/river channels across a floodplain

B horizon: horizon of accumulation and transformation in a soil, below the A and above the C horizon
Basic: or calcareous with a pH of >7
Basin mire: freshwater peat accumulation in a basin with impeded drainage and fed by calcareous groundwater; e.g. East Anglian fens
Bioturbation: mixing of the soil/sediment by the soil fauna
Blanket peat: upland, acidic peat formed as a result of high rainfall and an impermeable subsoil; e.g. on Dartmoor
Braided channel: meandering river channel system in a floodplain (or braid plain)
Brown earth: well structured, generally calcareous, soil exhibiting some weathering, and pedogenesis formed on well drained, neutral to calcareous subsoils/substrates
Buried soil (or old land surface, OLS): a soil formed under previous environmental conditions buried by later drift or erosion deposits and/or built structures of any age

C horizon: the geological hardrock or drift substate which weathers to create the soil above
Calcareous: or basic with a pH>7
Cambic B or Bw horizon: weathered B horizon of a brown earth
Cambisol: calcareous, clay/iron/calcium carbonate enriched brown earth
Catena: sequence of soil types on the same geology dependent on variable relief and drainage characteristics
Chelation: amino acids from the root complex combine with iron, aluminium, silica and magnesium and move down-profile with a pH is <5 when they become redeposited
Chernozem: organic and clay enriched brown earth of Russia and central Asia
Cicum-neutral: pH range of 6–7

Clastic: fine clay sediment
Coarse component: gravel and stone (>2 mm in diameter) component of a soil
Colluvium (hillwash): loose, non-stratified, ill-sorted, heterogeneous mixture of sediment of various size grades derived from soil/subsoil erosion upslope and redeposited at the base of slopes
Conductivity: measure of the total solute content of aqueous environments
Consistency: handling properties of a soil along with cohesion/adhesion, strength and cementation
Coppicing: deliberate, managed removal of branches of trees, such as willow and alder, to just above the base of the trunk
Cutan: clay coating, generally forming on the walls of the capillary voids in the lower or B horizon of a soil

DEM: Digital Elevation Model; essentially a geo-referenced 3-D terrain model of a landscape
Dendritic channel: channel system in the shape of an up-turned bare oak tree's branches; e.g. the later Neolithic tidal channel system of the East Anglian fenland basin
Desertification: long-term aridification and the creation of desert environments
Desiccation: drying-out of organic remains
Dirty clay: illuvial clay containing abundant silt-sized carbonised and/or amorphous organic matter fragments and punctuations
Dry valley: former stream valley, now dry, bissecting the slope; i.e. found in chalk downland landscapes of southern England
Dusty clay: illuvial clay containing micro-contrasted silt-sized particles of silt and fine organic matter
Dyke: drainage ditch in the East Anglian fens

Ecosystem: the living community (i.e. plants, animals, microbes) functioning together with the non-living environment (i.e. air, water, soil)
Eluvial/eluviation: removal of silt/clay/fine organic matter from an upper soil horizon (Ea or Eb) by processes such as leaching and groundwater percolation

Fen: colloquial term for a lowlying/lowland peat bog or marsh such as the East Anglian fenlands
Fen-edge or 'skirtland': seasonally wet margin of land with peat encroachment on the outer perimeter of a fen basin
Fen peat or basin peat: see basin mire above

Geoarchaeology: interlinked study of landforms, landscape change and human impact on the landscape through archaeological, geographical, geomorphological and soil science approaches
Geomorphology: the study of landforms
GIS: Geographical Information System; method of layering of different datasets in 3D on a DEM
Gleying: influence of groundwater leading to greater/lesser degree of waterlogging causing reduction of iron and manganese staining
Groundmass: the main mineral and organic components of soil and their arrangement and relationships to each other; generally composed of variable mixtures of very fine sand, silt and clay components as well as fine organic matter
Groundwater table: the interface between the saturation zone and the capillary fringe in a soil/sediment/geological substrate sequence
Gypsum: lenticular crystal composed of silica and oxygen, often associated with rapid drying conditions

Heath: lowland, heather and bracken dominated landscape associated with poorly drained, acidic, sandy subsoils, podzols and peat, generally found in north-western Europe
Humus: organic component of soils, as either plant tissue and/or amorphous matter; occurs in three types: mull (basic), moder (neutral) and mor (acidic)
Hydrolysis: reaction of disassociated hydrogen and hydroxide atoms of water with ions of mineral elements; it is measured by electrical conductivity
Hydromorphism: formed under waterlogged conditions

ICP-AES: Inductively Coupled Plasma–Atomic Emission Spectroscopy; a technique used to identify and quantify the elemental composition of a soil/sediment sample

Illuvial/illuviation: mobilisation, removal and redeposition of fines (silt, clay and organic matter) towards the base of the soil profile, generally occurring in the lower or B horizons of soils leaving a depleted or eluvial soil horizon above
Infiltration capacity: the ability of a soil or sediment to absorb surface and rain-water
Landscape: our surroundings - natural, human-modified and constructed
Leaching: removal of fines and nutrients of a soil through percolating groundwater
Lessivage: equates with eluvial/illuvial process of fines removal from upper soil horizons and their redeposition in a lower horizon; forms clay skins (cutans or coatings) on channels, pores and structural surfaces in soils, and often follows the acidification of base-rich soils
Lidar: Laser Illuminating Detection and Ranging; a remote sensing technology which measures distance by illuminating a target with a laser and analysing the reflected light; used to make high resolution land surface maps for archaeological and geomorphological feature detection purposes
Limpid clay: pure clay
Loam: an equal mix of sand, silt, clay and organic matter; gives optimum tilth and fertility for cultivation
Loess: windblown silt and very fine sand, usually 25–50 μm in size
Loss-on-ignition: method of determining the total organic content of a soil/sediment by burning off the organic content in a muffle furnace
Luminescence (TL) (or thermoluminescence): dating method for pottery based on the emission of light by quartz on the last heating of the object (Aitken 1985; Duller 2008)
Lynchet: earthen field boundary bank formed on slopes due to hillwash and ploughing processes, often directly associated with hedgerows

Magnetic susceptibility: measure of magnetic enhancement of the soil/sediment generally caused by burning
Mere: freshwater lake in a lowland basin fen or bog
Micromorphology: the study of soils/sediments in thin section using a polarising microscope
Microstructure: the within-ped organisation of a soil
Midden: deliberate accumulation of settlement debris/rubbish
Minerogenic: sand, silt and clay components of a soil or sediment
Mire: peat bog
Moder: organic horizon of a soil of neutral pH (6–7); characteristic of coniferous and deciduous woodland where the drainage is only moderate and there is high biological activity
Mor: organic horizon of a soil of acidic pH (<6); acidic humus; characteristic of soils under heath and coniferous forests with poor drainage
Mull: organic horizon of a soil of basic pH (>7); amorphous humus, well mixed with the soil; characteristic of base-rich soils with high faunal activity under deciduous forest on calcareous subsoils/substrates with good drainage
Multi-element analysis (or ICP-AES or ICP-MS): laboratory method of determining the frequency of all elements and heavy metals present in a small bulk sample of soil or sediment (i.e. Al, Ba, Ca, Cu, Fe, K, Mn, Mg, P, Sr, Zn) using Inductively Coupled Plasma-Atomic Emission Spectroscopy or Inductively Coupled Plasma-Mass Spectrometry methods

Nitrification: the transformation of ammonium salts to nitrates by bacteria in soils

Optically Stimulated Luminesence (OSL): dating method for soil/sediment horizons and surfaces using measurements of aliquots of medium-coarse quartz grains (Duller 2008; Murray and Wintle 2000; 2003)
Oxidation: opposite of reduction; oxygen dominates soil system, leading to formation of iron oxides and hydroxides and destruction of organic component of the soil; ferrous iron (Fe 2+) becomes ferric (Fe 3+) resulting in the precipitation of iron, usually as an oxide; disadvantageous for organic preservation

Palaeo-catena: sequence of buried soils on the same geological substrate which are dependent on variation in relief and drainage characteristics and the nature of burial
Palaeosol (or a buried soil): as found under either archaeological sites or monuments and under more recent drift deposits, and generally exhibiting soil characteristics no longer observed in the same locale today
Palaeo-channel: relict stream or river channel, usually of braided, meandering or anastomosing type
Palynology: study of pollen to interpret past vegetational assemblages and landscape change
Ped: main structural unit of organisation of a soil

Pedofeatures: discrete zones in soils distinguished from the groundmass and resulting from soil formation processes
Phytoliths: microscopic silica bodies in plant remains, mainly of grasses and sedges
Plasticity: measure of the percent water saturation required to make a soil/sediment mobile
Podzol: an acidic, leached and eluviated soil developed on acidic substrates with poor drainage characteristics, characterised by an eluviated lower A (or Ea) horizon and a spodic B horizon exhibiting either amorphous iron (Bs) or organic (Bh) accumulations or pans towards the base of the profile, and generally associated with acidic vegetation, thin blanket peat formation and impermeable and acidic subsoils/substrates
Podzolisation: process of leaching leading to the formation of podzol (as above)
Pollarding: the regular and deliberate chopping back of the upper story or crown of trees, especially alder and willow, as a form of woodland management and wood resource procurement
Proxy data: types of data used to reconstruct past environments (i.e. pollen, insects, molluscs)
Ranker (or incipient soil): a weakly developed soil, generally only exhibiting a thin organic A horizon (or Ah) over the weathered substrate (or B/C)
Raw soil: immature soil representing the first weathering and the beginnings of soil formation
Redox potential: measure of electrical activity in the groundwater system which gives an indication of the presence of oxidising or reducing conditions
Reduction: removal of oxygen in the soil water and the formation of ferrous iron (Fe 2+); associated with gleyed and waterlogged soils/sediments, and advantageous for all types of organic preservation
Rendzina: thin grassland soil developed on a calcareous parent material, generally composed of an amorphous, earthworm reworked, organic A horizon over a weathered B/C horizon, which is maintained by soil faunal mixing, primarily by earthworms
Resistant: the ability of a system to return to a state of equilibrium after a disturbance
Resilient: a measure of the system's ability to absorb and adapt to changes

Saltation: bouncing transport of wind-blown, generally silt-size material
Sediment: any inorganic/organic material ranging in size from a fine clay to coarse rock which has undergone weathering, transport and redeposition by various geographic agencies, which may or may not exhibit horizonation upon deposition
SEM (Scanning Electron Microscopy): a method of determining the chemical composition of soils/sediments and especially clay types and structures
Sesquioxides: oxides and hydroxides of iron and aluminium whose formation is generally associated with alternating wetting and drying soil conditions
Shear strength: measure of the degree of saturation required to make a soil slump downhill in one event
Soil: an inorganic/organic material developing through the weathering of earth's mantle by physical and chemical processes and geographic agents through time such that distinct horizonation occurs
Soil complex: the whole ecosystem of the soil
Soil creep: slow downslope movement of saturated soil under gravity
Soil texture: the relative proportions of sand, silt and clay in the soil
Solifluction: mass movement of unconsolidated sediment, gravel and stones under cold climate or periglacial conditions which is characterised by many different orientations of the gravel/stone component
Spodic horizon: an iron-enriched horizon (or Bs) found at the base of a podzol
Stagno-gley soil: gleyed or saturated, often peaty soil, with/without thin iron pans present

Tectonic: uplift and subsidence effects on landforms caused by volcanic eruptions and earth plate shifts
Textural pedofeatures: coatings and/or infillings of pure to intermixed clay, silt and very fine organic matter formed by the illuvial deposition down-profile of fine materials eluviated from upper layers by the soil water
Translocation: the transport of material within a soil, either in suspension or solution
Truncation: violent erosion or shearing and removal of some or all of soil profile downslope

Valley system: an area of landscape from watershed to watershed across a river valley
Vermiforms: worm-shaped pores in soils

XRF (X-ray Fluorescence): a non-destructive technique used to identify materials or elemental content